ESI 291

w/ 290R
840R
860R

ESI 291

esi®

# Instruction Manual

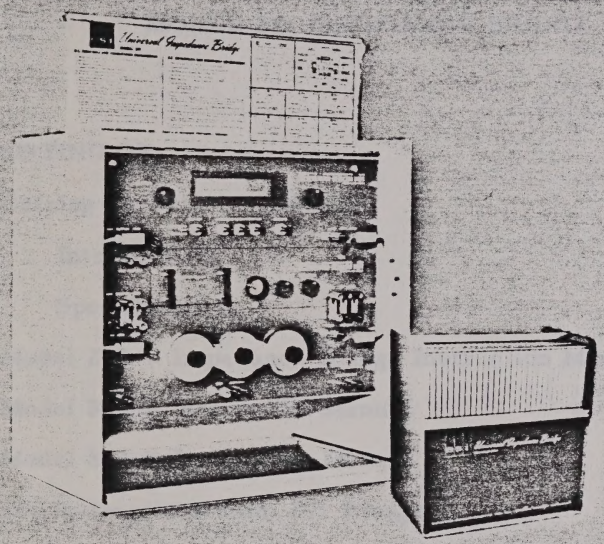
**ELECTRO - MEASUREMENTS INC.**

7524 S.W. MACADAM • PORTLAND 19, OREGON

**BRIDGES AND ACCESSORIES**

NOVEMBER 1959

REPLACES AUGUST 1958



**Model 291**

## IMPEDANCE BRIDGE

**including**

***Model 290-R***

## *IMPEDANCE BRIDGE*

***Model 840-R***

## *DC GENERATOR-DETECTOR*

***Model 860-R***

## *AC GENERATOR-DETECTOR*

*excellent scientific instruments*

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# INSTRUCTION MANUAL
# for
# MODEL 291 IMPEDANCE BRIDGE

CONSISTING OF:

Catalog Sheet C-13 including:

Introduction

Specifications

Model 290-R Impedance Bridge Instruction Manual

Model 840-R Instruction Manual

Model 860-R Instruction Manual

Lid Instructions from 291 Bridge

# SPECIFICATIONS

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| | MAGNITUDE | | D and Q | |
|---|---|---|---|---|
| | RANGE | ACCURACY | RANGE | ACCURACY |
| R | 0-1200 kilohms in 7 ranges* 0.1 milliohm per dial division on lowest R range | ± (0.1% + 1 dial div.), except ± (0.2% + 1 dial div.) on lowest R range | | |
| G | 0-1200 millimhos in 7 ranges 100 μμmhos (1/10,000 megohms) per dial division on lowest G range | ± (0.1% + 1 dial div.), except ± (0.2% + 1 dial div.) on lowest G range | | |
| L,Q | 0-1200 henrys in 7 ranges 0.1 μh per dial division on lowest L range | ± (0.3% + 1 dial div.), except ± (0.4% + 1 dial div.) on lowest L range | Q = 0 to 10.5 x $f_{kc}$ in 3 ranges 0.001 x $f_{kc}$ per dial division on lowest Q range | 1/Q = ±(2% + 0.01 x $f_{kc}$) except ±(2% + 0.04 x $f_{kc}$) on highest L range |
| L,D | 0-1200 henrys in 7 ranges 0.1 μh per dial division on lowest L range | ± (0.3% + 1 dial div.), except ± (0.4% + 1 dial div.) on lowest L range | D = 0 to 10.5 x $f_{kc}$ in 3 ranges 0.001 x $f_{kc}$ per dial division on lowest D range | D = ±(2% + 0.01 x $f_{kc}$), except ±(2% + 0.04 x $f_{kc}$) on highest L range |
| C,D | 0-1200 microfarads in 7 ranges 0.1 μμf per dial division on lowest C range | ± (0.2% + 1 dial div.), except ± (0.3% + 1 dial div.) on highest C range | D = 0 to 10.5 x $f_{kc}$ in 3 ranges 0.001 x $f_{kc}$ per dial division on lowest D range | D = ±(2% + 0.01 x $f_{kc}$), except ±(2% + 0.04 x $f_{kc}$) on lowest C range |
| C,Q | 0-1200 microfarads in 7 ranges 0.1 μμf per dial division on lowest C range | ± (0.2% + 1 dial div.), except ± (0.3% + 1 dial div.) on highest C range | Q = 0 to 10.5 x $f_{kc}$ in 3 ranges 0.001 x $f_{kc}$ per dial division on lowest Q range | 1/Q = ±(2% + 0.01 x $f_{kc}$) except ±(2% + 0.04 x $f_{kc}$) on lowest C range |

*Equivalent resistance measurements to 10,000 megohms are possible using the conductance ranges.

Accuracy statements apply at 1 kc. Errors may be slightly larger at frequency extremes.

## GENERATOR

**Voltages:** Dc outputs of 10 volts with internal resistance of 60 ohms and 300 volts with internal resistance of 22K ohms.

**Power:** Power output limited to 1 watt by internal series resistance.

**Polarity:** Polarity of voltage at output terminals may be reversed by a front panel control.

## DETECTOR

**Galvanometer:** The light beam type galvanometer has a sensitivity of approximately 30 millimeters per microampere. It has an internal resistance of approximately 300 ohms, and is critically damped by approximately 2,000 ohms.

**Sensitivity:** Three-position switches on the front panel select the desired galvanometer sensitivity. Sensitivities available are 0.03, 0.60, and 12 microamperes per millimeter division.

**Zero-Set:** A knob on the front panel provides for adjustment of the galvanometer zero position.

**Damping:** A three-position switch on the front panel selects the damping condition when using maximum galvanometer sensitivity.

## POWER SUPPLY

115 volts or 230 volts, 50/60 cycles. Voltage choice is by means of internal wiring change.

## PROTECTION

Circuit is designed so dc power output, at either 10 volts or 300 volts, cannot exceed 1 watt. Detector cannot be damaged by power from 840-R generator section.

## DIMENSIONS — MOUNTING

Instrument is designed for standard racks having 19" width; panel height 5¼"; depth behind panel approximately 8". Weight is 12 pounds net.

## GENERATOR

**Voltage:** The generator voltage is adjustable from 0 to approximately 15 volts, with an internal resistance of approximately 600 ohms. Each generator output terminal is insulated from ground and has a capacitance to ground of less than 30 micromicrofarads.

**Frequency:** The operating frequency is determined by the plug-in network, and is accurate to ±1%. A 1 kilocycle unit is supplied with the bridge. Units for 0.1, 0.4, and 10 kilocycles are available from stock. Special networks for any frequency between 0.1 and 10 kilocycles can be made to order.

## DETECTOR

**Indicator:** An electron ray null indicator is used because of its instantaneous response to signal changes. This prevents passing a null without knowing it. A dual display presents changes in either strong or weak signals.

**Sensitivity:** At maximum detector gain the lower half of the eye responds to signals between approximately 20 microvolts and 0.01 volts. The upper eye responds to signals between 0.01 volts and 5 volts.

**Frequency:** The detector is sharply tuned to the generator frequency in order to minimize response to harmonics and hum pickup. The detector and generator tuning networks are contained in the same plug-in unit. The detector response to the second harmonic of the generator frequency is down at least 30 decibels.

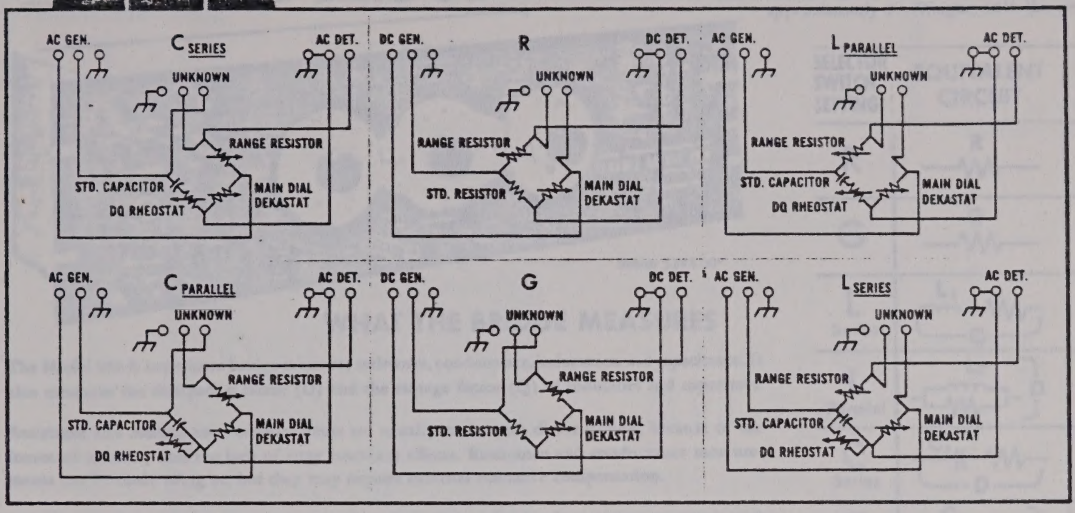
## POWER SUPPLY

115 volts, 50/60 cycles. 230 volt transformer is available.

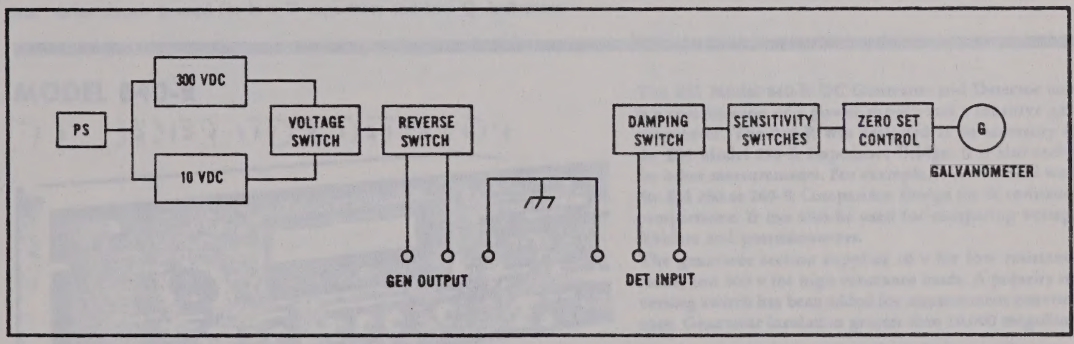
## DIMENSIONS — MOUNTING

Instrument is designed for standard racks having 19" width; panel height 3½"; depth behind panel approximately 8". Weight is 10 pounds net.

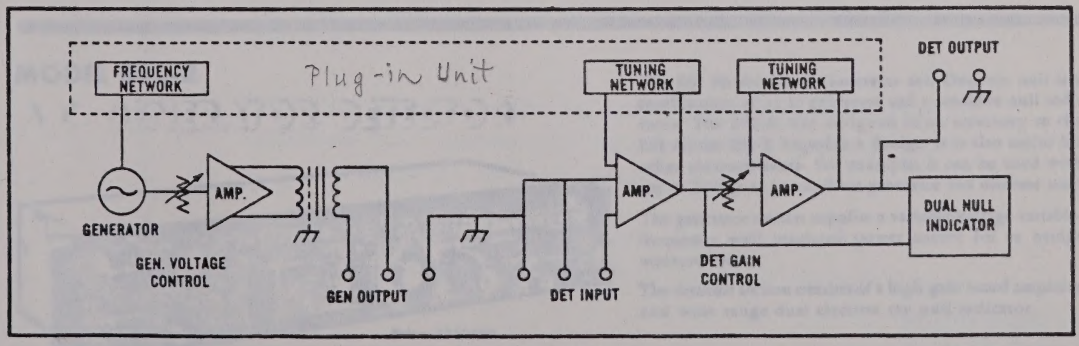
## MODEL 290-R IMPEDANCE BRIDGE




## MODEL 840-R D. C. GENERATOR-DETECTOR




## MODEL 860-R A. C. GENERATOR-DETECTOR



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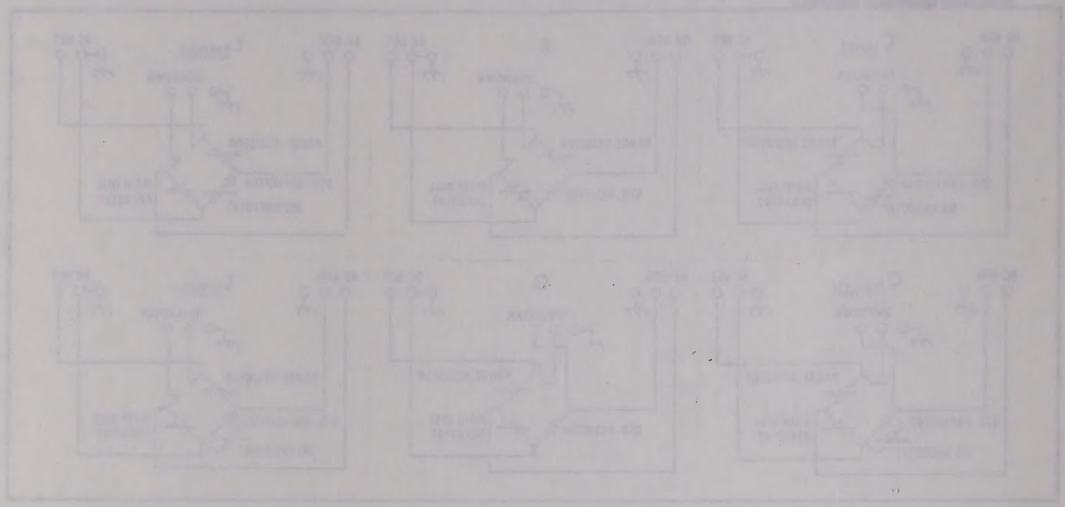
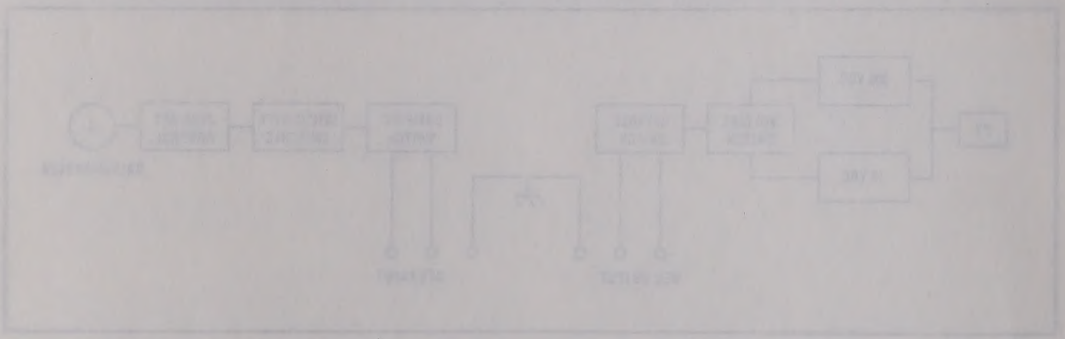
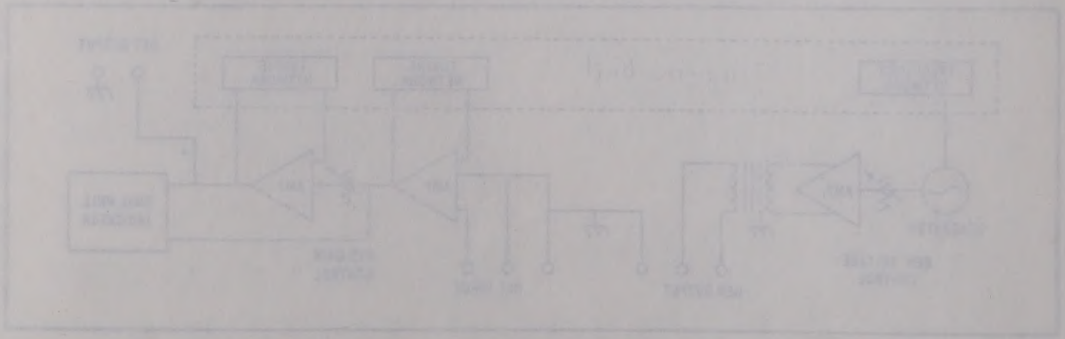
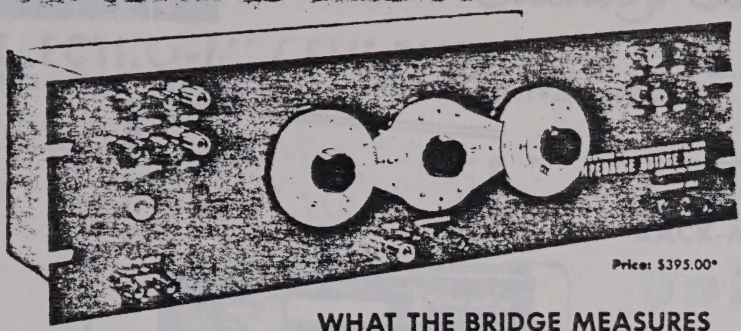






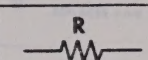
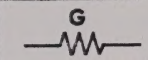
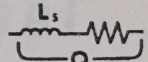
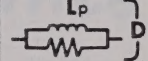
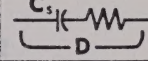
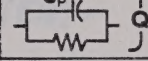
## MODEL 290-R

# UNIVERSAL IMPEDANCE BRIDGE



Price: $395.00*

Panel width: 19", fits standard rack. Panel height: 5¼". Depth behind panel: approximately 8". Weight: 18½ lbs. net.

| SELECTOR SWITCH SETTING | EQUIVALENT CIRCUIT |
|---|---|
| R |  |
| G |  |
| L Series |  |
| L Parallel |  |
| C Series |  |
| C Parallel |  |

## WHAT THE BRIDGE MEASURES

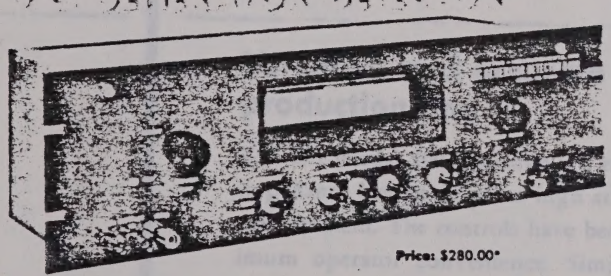
The Model 290-R impedance bridge measures resistance, conductance, inductance, and capacitance. It also measures the dissipation factor (D) and the storage factor (Q) of inductors and capacitors.

Resistance and conductance measurements are usually made with direct current because of the increased accuracy and the lack of stray reactance effects. Resistance and conductance measurements can be made using ac, but they may require external reactance compensation.

Inductance and capacitance measurements are made in terms of a simple two-element circuit with the same impedance as the unknown. The bridge dials read the values of this equivalent circuit. An equivalent parallel circuit is used for high Q inductors and high D capacitors. An equivalent series circuit is used for low D capacitors and low Q inductors.

## MODEL 840-R

# D. C. GENERATOR DETECTOR



Price: $280.00*

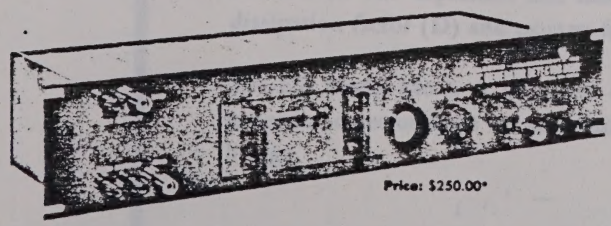
The ESI Model 840-R DC Generator and Detector unit is a combination of a power supply and a sensitive galvanometer. The 840-R was designed as an accessory to the ESI Model 290-R Impedance Bridge. It is also useful for other measurements. For example, it can be used with the ESI 260 or 260-R Comparison Bridge for dc resistance comparisons. It can also be used for comparing voltage dividers and potentiometers.

The generator section supplies 10 v for low resistance loads, and 300 v for high resistance loads. A polarity reversing switch has been added for measurement convenience. Generator insulation greater than 10,000 megohms.

The detector section consists of a light beam galvanometer and associated zero-set, damping, and sensitivity controls.

## MODEL 860-R

# A. C. GENERATOR DETECTOR



Price: $250.00*

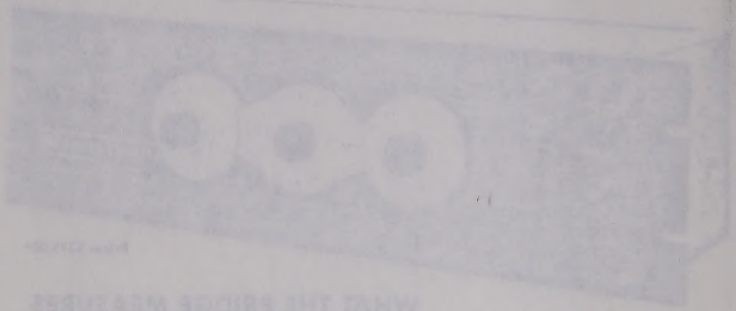
The ESI Model 860-R Generator and Detector unit is a combination of an ac generator and a sensitive null indicator. The 860-R was designed as an accessory to the ESI Model 290-R Impedance Bridge. It is also useful for other measurements. For example, it can be used with any ac bridge as an auxiliary generator and detector unit.

The generator section supplies a variable-voltage variable-frequency well insulated power source for ac bridge measurements.

The detector section consists of a high-gain tuned amplifier and wide range dual electron ray null indicator.

*Complete unit, model 291 as pictured on front page, with customed enclosure . . . priced at $995.00.

All prices f.o.b. Portland, Oregon.



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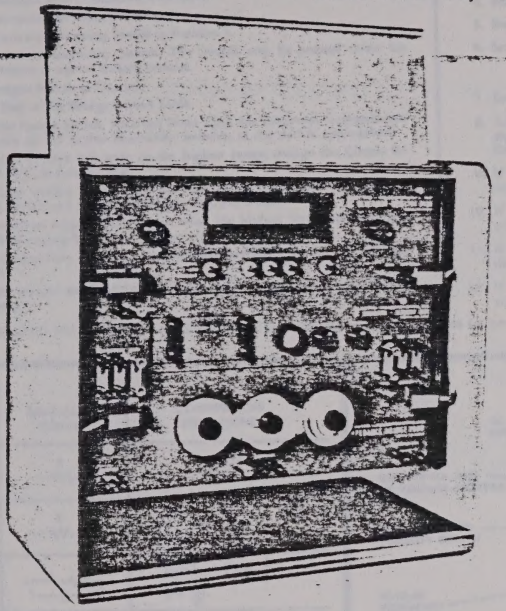
Catalog Sheet

C-13

ELECTRO-MEASUREMENTS, INC.
7524 S. W. MACADAM • PORTLAND 19, OREGON

APRIL 1959
REPLACES JUNE 1957



Combined units with cabinet as pictured . . . MODEL 291

**MODEL 290-R**
**RACK-MOUNTED**

# universal impedance bridge

**WITH MODEL 840-R**
**D.C. GENERATOR-DETECTOR**

**AND MODEL 860-R**
**A.C. GENERATOR-DETECTOR**

## Versatile and accurate in the lab and on the production line

The ESI Model 290-R bridge is a rack-mounted, general-purpose impedance bridge. It offers high accuracy and great flexibility of measurement. The controls have been human-engineered for maximum operator convenience. Simple operation and error-free, direct-line readout are made possible by the ESI DEKADIAL® coaxial controls.

The bridge measures resistance, conductance, capacitance, and inductance. For capacitors and inductors, it also measures the dissipation factor (D) and storage factor (Q).

The ESI Model 840-R dc generator-detector and Model 860-R ac generator-detector units are especially designed for use with this bridge.

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# Universal Impedance Bridge

## MODEL 291

### DC RESISTANCE AND CONDUCTANCE MEASUREMENTS

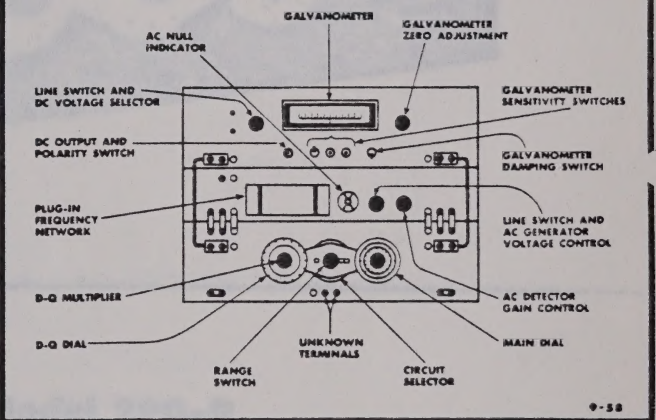
1. Set the Output and Sensitivity Switches to the Center Position (Off).
2. Set the Circuit Selector to R or G.
3. Set the DC Voltage Selector to 10 V.
4. Connect the Resistor to the Unknown Terminals.
5. Adjust the Galvanometer Zero, if necessary.
6. Set the Galvanometer Damping Switch to Position 3.
7. Turn on the lowest Sensitivity Switch. The Switch may be pressed down for momentary contact, or up for locking contact.
8. Set the DC Output Switch to Normal.
9. Set the Main Dial of the Bridge to read 3.000.
10. Adjust first the Range Switch, then the Main Dial, for minimum Galvanometer deflection. Turn on the higher Sensitivity Switches as the null is approached.
11. If the balance is beyond full scale on the highest range, change the Circuit Selector from R to G, or from G to R.
12. If the Main Dial reading at balance is less than 1.200, use the next lower setting of the Range Switch and re-adjust the Main Dial for a null.
13. If the Galvanometer response is sluggish when the highest Sensitivity Switch is on, change the Damping Switch to Position 2 or 1.
14. For increased sensitivity on high resistance measurements set the DC Voltage Selector to 300 V.
15. Return the DC Output and Sensitivity Switches to Off Position before disconnecting the Resistor.

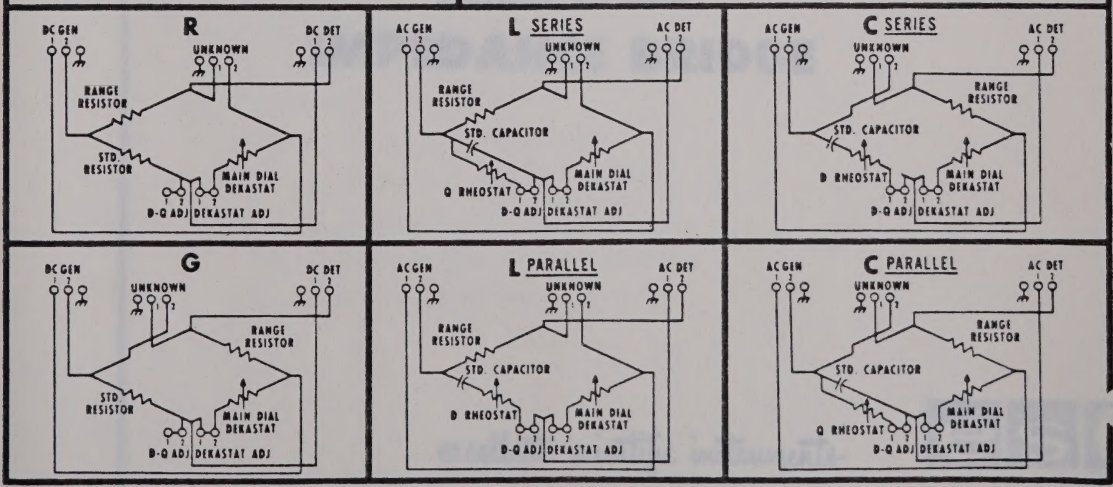
### AC CAPACITANCE AND INDUCTANCE MEASUREMENTS

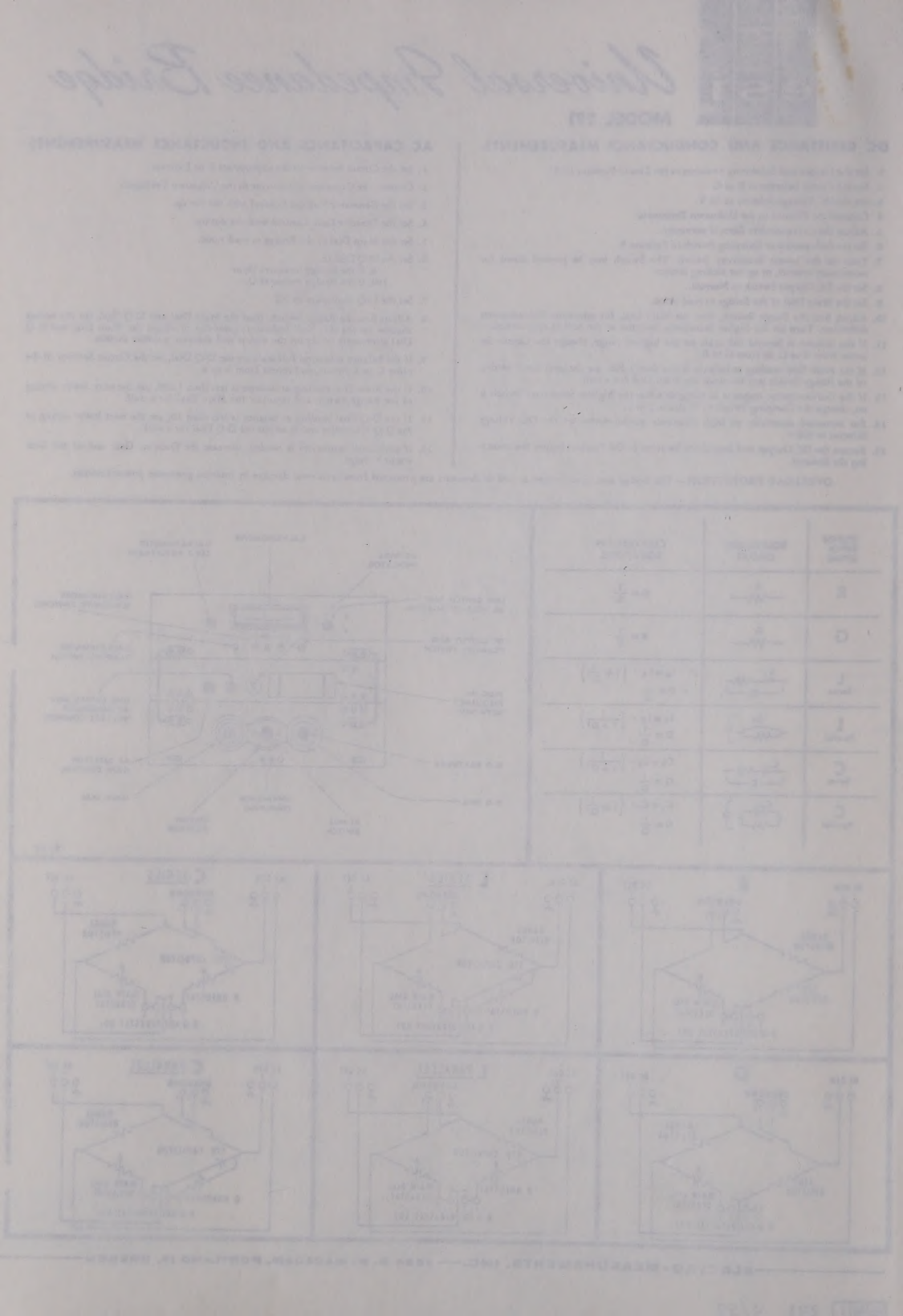
1. Set the Circuit Selector to the appropriate C or L circuit.
2. Connect the Capacitor or Inductor to the Unknown Terminals.
3. Set the Generator Voltage Control with the dot up.
4. Set the Detector Gain Control with the dot up.
5. Set the Main Dial of the Bridge to read 3.000.
6. Set the D-Q Dial to
   0, if the Bridge measures D; or
   100, if the Bridge measures Q.
7. Set the D-Q Multiplier to .1X.
8. Adjust first the Range Switch, then the Main Dial and D-Q Dial, for the widest shadow on the AC Null Indicator. Continue to adjust the Main Dial and D-Q Dial alternately to obtain the widest and sharpest possible shadow.
9. If the balance is beyond full scale on the D-Q Dial, set the Circuit Selector to the other C or L circuit, and repeat from Step 6.
10. If the Main Dial reading at balance is less than 1.200, use the next lower setting of the Range Switch and re-adjust the Main Dial for a null.
11. If the D-Q Dial reading at balance is less than 10, use the next lower setting of the D-Q Multiplier and re-adjust the D-Q Dial for a null.
12. If additional sensitivity is needed, increase the Detector Gain and/or the Generator Voltage.

OVERLOAD PROTECTION—The bridge and its associated ac and dc detectors are protected from accidental damage by internal generator power limiting.

| SELECTOR SWITCH SETTING | EQUIVALENT CIRCUIT | CONVERSION EQUATIONS |
|---|---|---|
| R | R | $G = \frac{1}{R}$ |
| G | G | $R = \frac{1}{G}$ |
| L Series | $L_s$ in series with Q | $L_p = L_s \cdot \left(1 + \frac{1}{Q^2}\right)$ <br> $D = \frac{1}{Q}$ |
| L Parallel | $L_p$ in parallel with D | $L_s = L_p \cdot \left(\frac{1}{1+D^2}\right)$ <br> $Q = \frac{1}{D}$ |
| C Series | $C_s$ in series with D | $C_p = C_s \cdot \left(\frac{1}{1+D^2}\right)$ <br> $Q = \frac{1}{D}$ |
| C Parallel | $C_p$ in parallel with Q | $C_s = C_p \cdot \left(1 + \frac{1}{Q^2}\right)$ <br> $D = \frac{1}{Q}$ |





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**BRIDGES AND ACCESSORIES**

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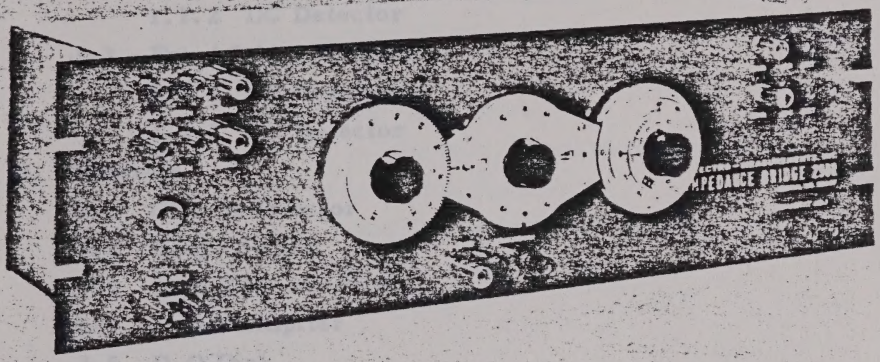
NOVEMBER 1959
REPLACES AUGUST 1958



# Model 290-R
# IMPEDANCE BRIDGE

*excellent scientific instruments*

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INSTRUCTION MANUAL

for

MODEL 290-R UNIVERSAL IMPEDANCE BRIDGE

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## 1. ACCESSORIES REQUIRED

### 1.1 For DC Measurements:

The ESI Model 840-R dc Generator and Detector is recommended for use with the Model 290-R bridge. If other dc generator and detector units are used, they should meet the following specifications:

#### 1.1.1 DC Generator

Do not exceed 400 volts open circuit.

Limit power output to 1 watt or less

For example:

1.5 volts in series with 0.5 ohms or more
10 volts in series with 25 ohms or more
300 volts in series with 25K ohms or more

#### 1.1.2 DC Detector

Desired characteristics:

Sensitivity: Approximately 0.03 microamperes per millimeter. Critically damped by a few kilohms.

### 1.2 For AC Measurements:

The ESI Model 860-R ac Generator and Detector unit is recommended for use with the Model 290-R bridge. If other ac generator and detector units are used, they should meet the following specifications:

#### 1.2.1 AC Generator

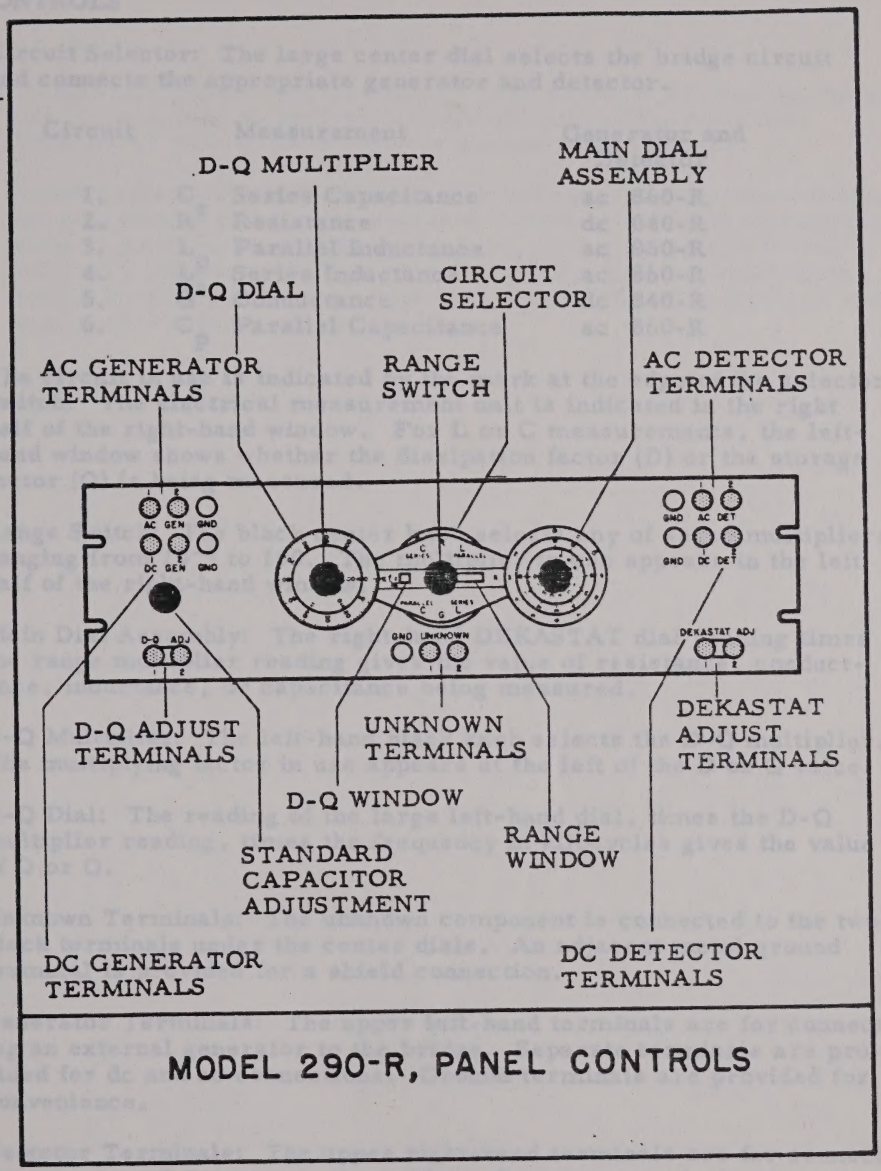
Desired characteristics:

Frequency Range: 0.1 kc to 10 kc
Output Voltage: 0 to 20 volts open circuit
Series Protective Resistor: 100 ohms or more

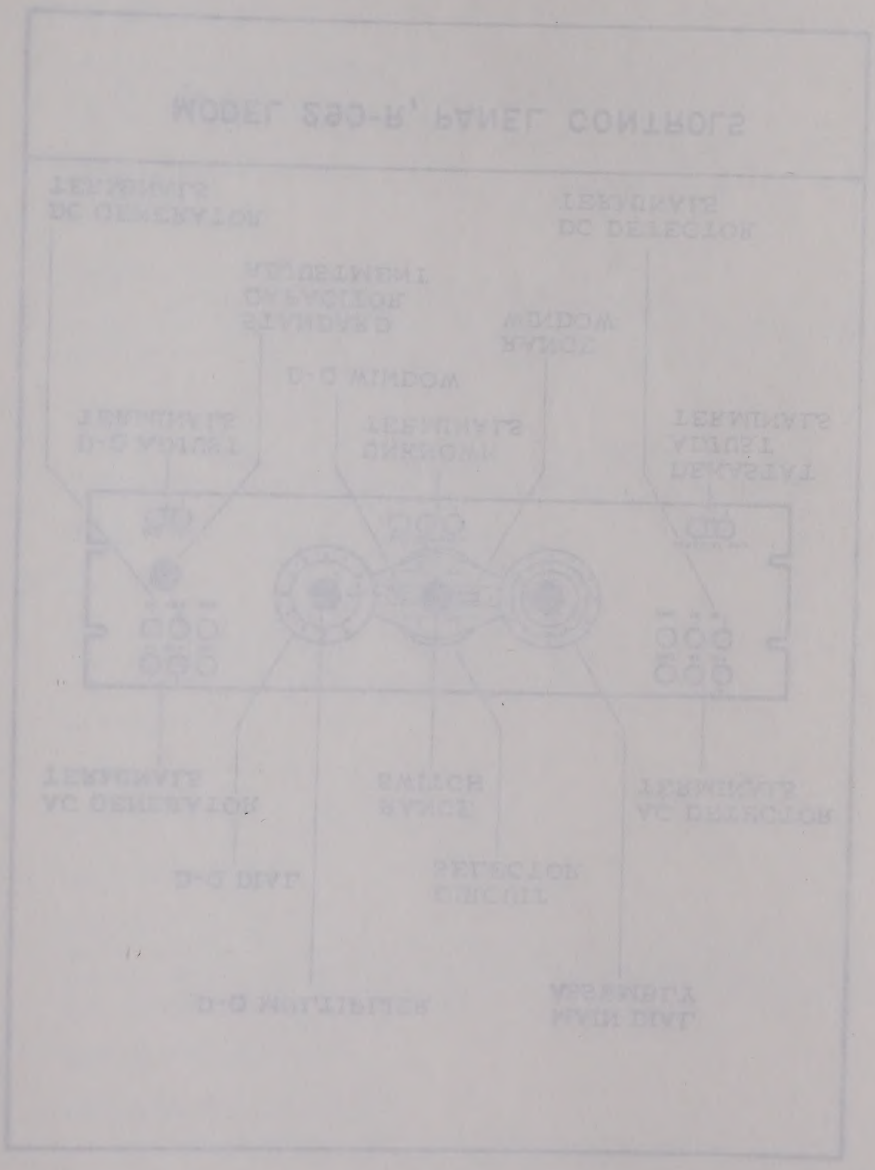
#### 1.2.2 AC Detector

Desired characteristics:

Sensitivity: 20 microvolts
Input Impedance: 500K ohms
Harmonic Suppression: 20db by 2nd harmonic




MODEL 290-R, PANEL CONTROLS



## 2. CONTROLS

2.1 Circuit Selector: The large center dial selects the bridge circuit and connects the appropriate generator and detector.

| Circuit | | Measurement | Generator and Detector |
|---|---|---|---|
| 1. | $C_s$ | Series Capacitance | ac 860-R |
| 2. | $R^s$ | Resistance | dc 840-R |
| 3. | $L_p$ | Parallel Inductance | ac 860-R |
| 4. | $L^p$ | Series Inductance | ac 860-R |
| 5. | $G^s$ | Conductance | dc 840-R |
| 6. | $C_p$ | Parallel Capacitance | ac 860-R |

The circuit in use is indicated by the mark at the edge of the selector switch. The electrical measurement unit is indicated in the right half of the right-hand window. For L or C measurements, the left-hand window shows whether the dissipation factor (D) or the storage factor (Q) is being measured.

2.2 Range Switch: The black center knob selects any of seven multipliers ranging from $10^{-4}$ to 100. The multiplier in use appears in the left half of the right-hand window.

2.3 Main Dial Assembly: The right-hand DEKASTAT dial reading times the range multiplier reading gives the value of resistance, conductance, inductance, or capacitance being measured.

2.4 D-Q Multiplier: The left-hand black knob selects the D-Q multiplier. The multiplying factor in use appears at the left of the D or Q value.

2.5 D-Q Dial: The reading of the large left-hand dial, times the D-Q multiplier reading, times the frequency in kilocycles gives the value of D or Q.

2.6 Unknown Terminals: The unknown component is connected to the two black terminals under the center dials. An adjacent metal ground terminal is provided for a shield connection.

2.7 Generator Terminals: The upper left-hand terminals are for connecting an external generator to the bridge. Separate terminals are provided for dc and ac connections. Ground terminals are provided for convenience.

2.8 Detector Terminals: The upper right-hand terminals are for connecting an external detector to the bridge. Separate terminals are provided for dc and ac connections. Ground terminals are provided for convenience.

2.9 D-Q Adjustment Terminals: The lower left-hand terminals are for attaching an external circuit element to the D-Q arm of the bridge for special measurements.

2.10 DEKASTAT Adjustment Terminals: The lower right-hand terminals are for attaching an external circuit element to the main dial DEKASTAT arm of the bridge for special measurements.

2.11 Standard Capacitor Adjustment: The left center hole cover conceals the adjusting screw for the standard capacitor. Setting this adjustment to give the correct bridge reading for an accurately known value of capacitance (0.1 μf recommended) assures a short term bridge accuracy rating improvement of 0.1% for all inductance and capacitance measurements.

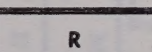
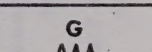
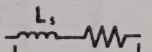
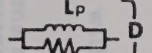
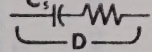
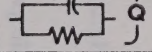
# 3. OPERATING INSTRUCTIONS

## 3.1 WHAT THE BRIDGE MEASURES

The ESI Model 290-R Impedance Bridge measures resistance, conductance, inductance, and capacitance. It also measures the dissipation factor (D) and the storage factor (Q) of inductors and capacitors.

Resistance and conductance measurements are usually made with direct current because of the increased accuracy and the lack of hum pickup and stray capacitance effects. Resistance and conductance measurements can be made using ac, but they may require external reactance compensation.

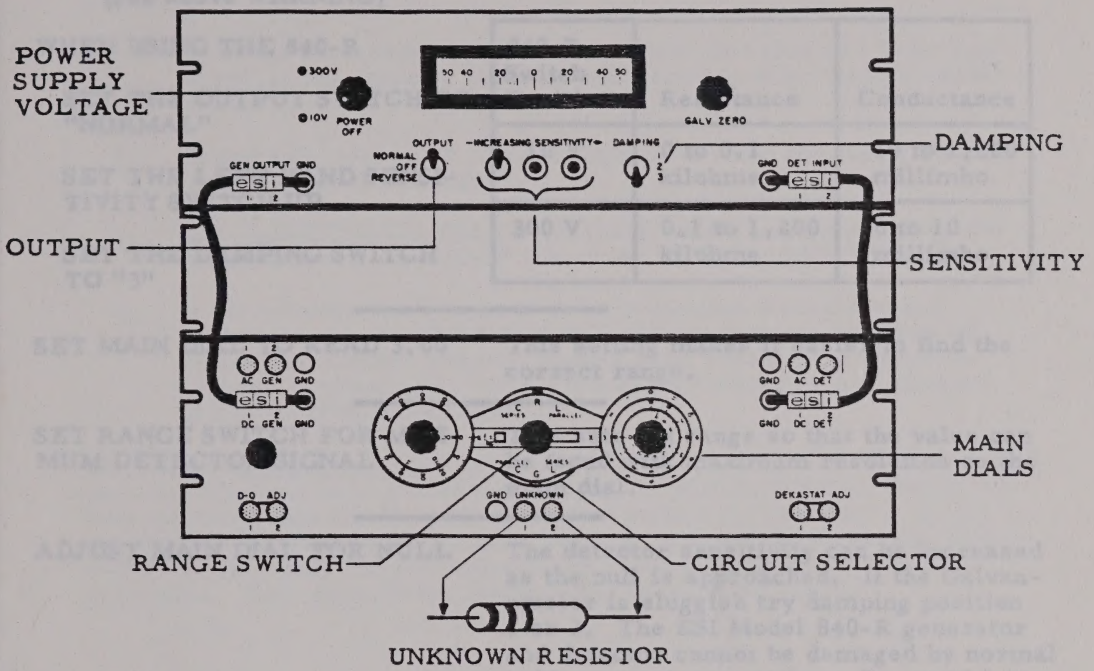
Inductance and capacitance measurements are made in terms of a simple two-element circuit with the same impedance as the unknown. The bridge dials read the values of this equivalent circuit. To achieve highest measurement accuracy, an equivalent parallel circuit is used for high Q inductors and high D capacitors. An equivalent series circuit is used for low D capacitors and low Q inductors.

| Selector Switch Setting | Equivalent Circuit | Magnitude | | Frequency | D and Q | | | Recommended Generator and Detector |
|---|---|---|---|---|---|---|---|---|
| | | Range | Smallest Step On Lowest Range | | | Range | Smallest Step On Lowest Range | |
| R |  | 0 to 1200 kilohms | $10^{-7}$ kilohms (0.1 milliohm) | dc * | | | | ESI 840-R |
| G |  | 0 to 1200 millimhos | $10^{-7}$ millimhos (100μμmho) | dc * | | | | ESI 840-R |
| L Series |  | 0 to 1200 henries | $10^{-7}$ henries (0.1 μh) | 0.1 kc<br>1 kc<br>10 kc | Q | 0 to 1.05<br>0 to 10.5<br>0 to 105 | 0.0001<br>0.001<br>0.01 | ESI 860-R |
| L Parallel |  | 0 to 1200 henries | $10^{-7}$ henries (0.1 μh) | 0.1 kc<br>1 kc<br>10 kc | D | 0 to 1.05<br>0 to 10.5<br>0 to 105 | 0.0001<br>0.001<br>0.01 | ESI 860-R |
| C Series |  | 0 to 1200 microfarads | $10^{-7}$ microfarads (0.1 μμf) | 0.1 kc<br>1 kc<br>10 kc | D | 0 to 1.05<br>0 to 10.5<br>0 to 105 | 0.0001<br>0.001<br>0.01 | ESI 860-R |
| C Parallel |  | 0 to 1200 microfarads | $10^{-7}$ microfarads (0.1 μμf) | 0.1 kc<br>1 kc<br>10 kc | Q | 0 to 1.05<br>0 to 10.5<br>0 to 105 | 0.0001<br>0.001<br>0.01 | ESI 860-R |

* Resistance and conductance measurements can be made using ac, but they may require external reactance compensation.

## 3.2 RESISTORS

### 3.2.1 MEASURING RESISTORS *the esi way*




**CONNECT DC GENERATOR AND DETECTOR**

Connect the external dc generator and detector to the dc terminals. They will be connected to the correct bridge circuits by the circuit selector.

> WARNING: Limit the generator output to one watt maximum. The ESI Model 840-R dc generator and detector has this protective feature built in.

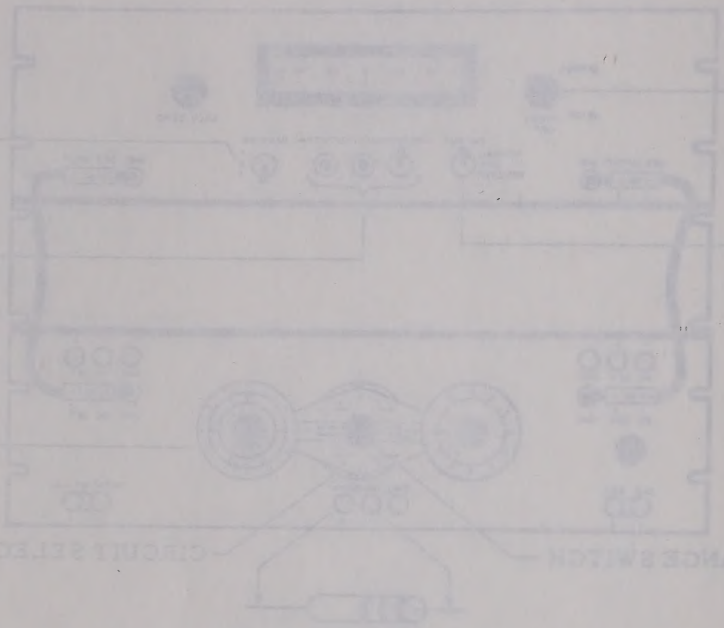
**CONNECT RESISTOR TO UNKNOWN TERMINALS**

Make good contact with the terminals.

**SET CIRCUIT SELECTOR TO R OR G**

$$R \text{ in kilohms} = \frac{1}{G \text{ in millimhos}}$$

If between 0.83 ohms and 1.2 megohms, measure either RESISTANCE or CONDUCTANCE. If less than 0.83 ohms (>1.2 mho), measure RESISTANCE. If greater than 1.2 megohms (<0.83 micromhos), measure CONDUCTANCE.



3.2.1 MEASURING RESISTORS (Cont.)

SET POWER SUPPLY VOLTAGE AND DETECTOR SENSITIVITY

(See above WARNING)

When using the ESI 840-R generator and detector, the voltage settings shown below will give maximum sensitivity.

WHEN USING THE 840-R

SET THE OUTPUT SWITCH TO "NORMAL"

SET THE LEFT HAND SENSITIVITY SWITCH UP

SET THE DAMPING SWITCH TO "3"

| 840-R Switch Position | Resistance | Conductance |
|---|---|---|
| 10 V | 0 to 0.1 kilohms | 10 to 1,200 millimho |
| 300 V | 0.1 to 1,200 kilohms | 0 to 10 millimho |

---

SET MAIN DIAL TO READ 3.00

This setting makes it easier to find the correct range.

---

SET RANGE SWITCH FOR MINIMUM DETECTOR SIGNAL

This sets the range so that the value can be found with maximum resolution on the main dial.

---

ADJUST MAIN DIAL FOR NULL

The detector sensitivity can be increased as the null is approached. If the Galvanometer is sluggish try damping position 1 or 2. The ESI Model 840-R generator and detector cannot be damaged by normal bridge use at any setting. Be careful to avoid damage if any other detector is used.

---

IF THE MAIN DIAL READING IS LESS THAN 1.200, USE THE NEXT LOWER RANGE AND READJUST MAIN DIAL FOR NULL

This takes advantage of the increased resolution near full scale of the dial.

3.2.2 THINGS TO WATCH OUT FOR

3.2.2.1 HIGH RESISTANCE MEASUREMENTS

Care must be taken to avoid leakage resistance across the unit being measured. If an electronic null detector is being used it may be affected by ac hum picked up by the leads.

### 3.2.2.2 LOW RESISTANCE MEASUREMENTS

On the low resistance ranges the lead resistance in the unknown arm becomes significant. A correction for this resistance can be made as follows:

1. Short the test leads together at the point that they are to be connected to the unknown resistor and measure this "ZERO RESISTANCE".

2. Connect the test leads to the unknown resistor and measure the "RESISTANCE READING".

3. The "RESISTANCE VALUE" of the unknown resistor is then the "RESISTANCE READING" minus the "ZERO RESISTANCE".

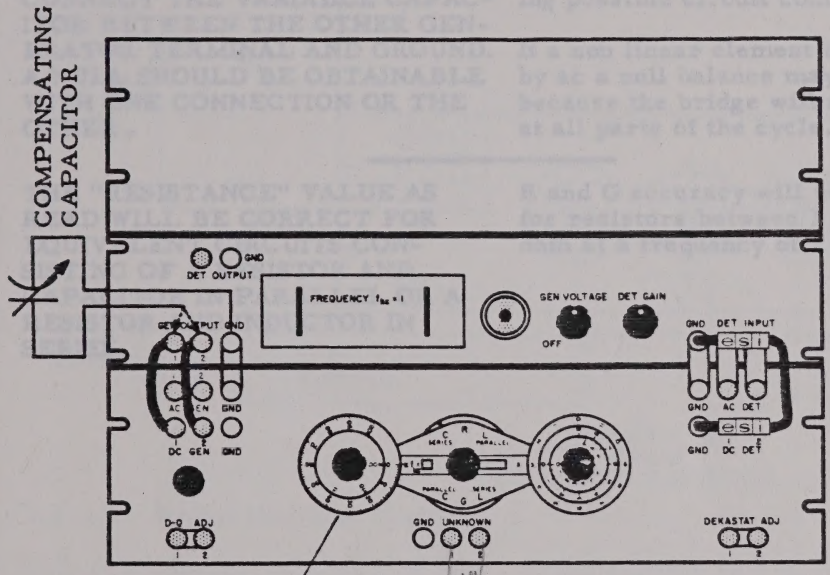
4. If the unknown resistance is to be connected directly to the terminals, the "ZERO RESISTANCE" reading can be taken by connecting a piece of heavy copper wire between the unknown resistance terminals. (#14 AWG copper wire has a resistance of about 0.00025 ohm/inch.)

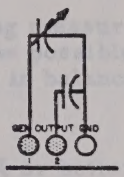
Sometimes thermal voltages are generated at connections and these can lead to erroneous balances of the bridge. If this condition is suspected, balance the bridge and then set the output switch to "reverse". If this results in a different galvanometer reading, change the main dial DEKASTAT® setting until the galvanometer reads the same for both output polarities. This cancels the effect of the thermal voltages.

## 3.2.3 MEASURING AC RESISTANCE *the esi way*

For greatest accuracy resistors should always be measured with dc. The accuracy of ac measurement will be 0.3% for one kilocycle and below over the range from one ohm to one megohm.

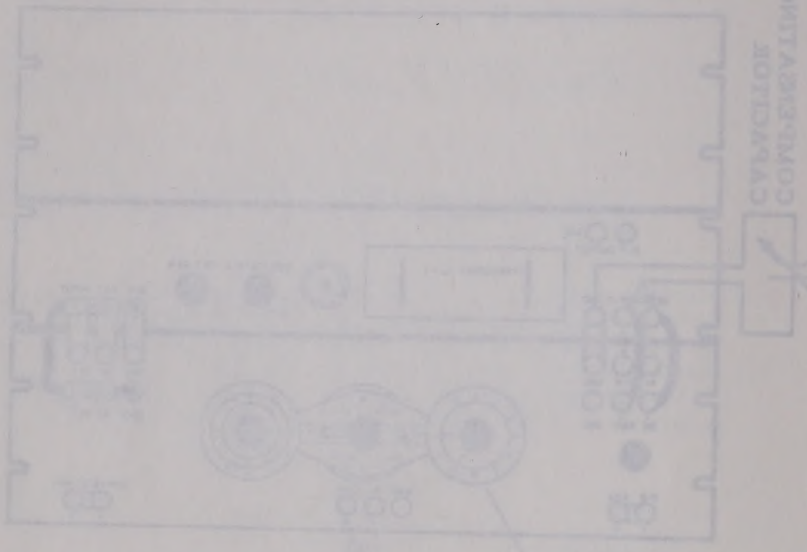
The indicated connections for the phase correction capacitor compensate for series inductance or parallel capacitance. It is impossible to seperate the correction for the unknown from that for the rest of the bridge circuit. If large reactances are involved the circuit should be measured as a capacitance or inductance and the resistance calculated.




NOTE:
If the phase correction is small it may be convenient to connect a fixed capacitor to one terminal and a variable one to the other.

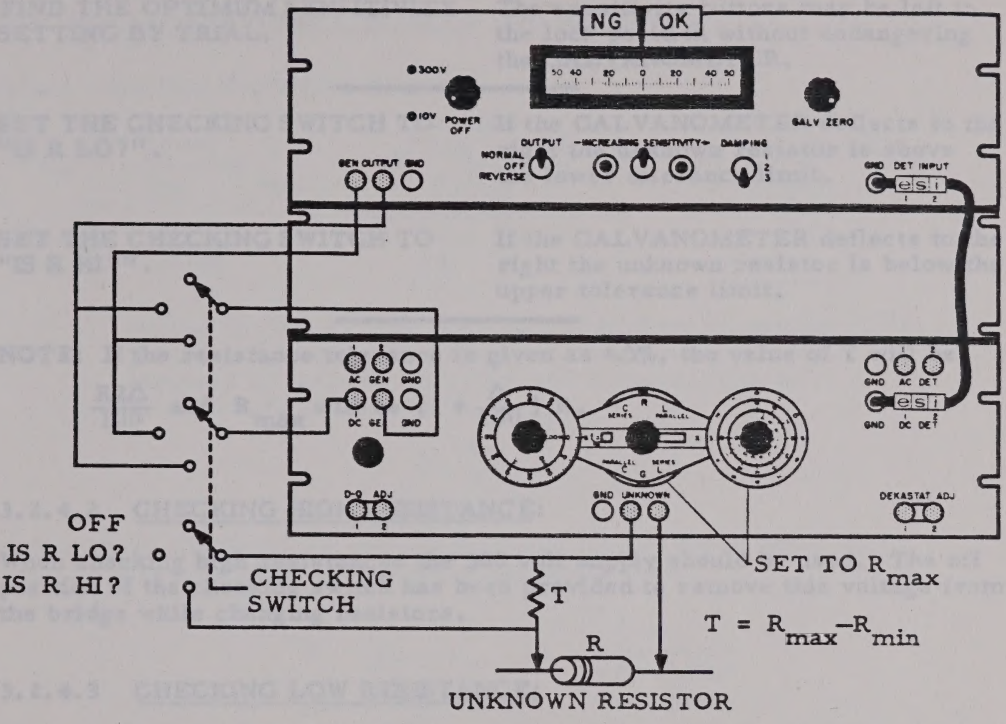
| | |
|---|---|
| REMOVE THE AC GENERATOR CONNECTING STRAPS | The ac detector straps need not be removed |
| CONNECT THE BRIDGE DC GENERATOR AND DETECTOR TERMINALS TO THE AC GENERATOR AND DETECTOR | Short lengths of open-wire leads for the generator will minimize errors |
| SET THE BRIDGE ON THE R OR G RANGE | This connects the desired bridge circuit |
| TRY TO BALANCE THE BRIDGE AS WITH DC | Usually the eye will not completely open, thus indicating uncompensated phase shift |



| | |
|---|---|
| CONNECT A VARIABLE CAPACITOR FROM GROUND TO ONE OF THE GENERATOR TERMINALS AND TRY TO OBTAIN A NULL WITH IT AND THE MAIN DIALS. | Connecting the capacitor from ground to either generator terminal permits compensation for some of the possible circuits of the unknown. |
| IF A NULL CANNOT BE REACHED, CONNECT THE VARIABLE CAPACITOR BETWEEN THE OTHER GENERATOR TERMINAL AND GROUND. A NULL SHOULD BE OBTAINABLE WITH ONE CONNECTION OR THE OTHER. | This permits balance over the remaining possible circuit combinations.<br><br>If a non linear element is being measured by ac a null balance may not be possible because the bridge will not be in balance at all parts of the cycle. |
| THE "RESISTANCE" VALUE AS READ WILL BE CORRECT FOR EQUIVALENT CIRCUITS CONSISTING OF A RESISTOR AND CAPACITOR IN PARALLEL OR A RESISTOR AND INDUCTOR IN SERIES. | R and G accuracy will be 0.3% or better for resistors between 1 ohm and 1 megohm at a frequency of 1 kc or less. |

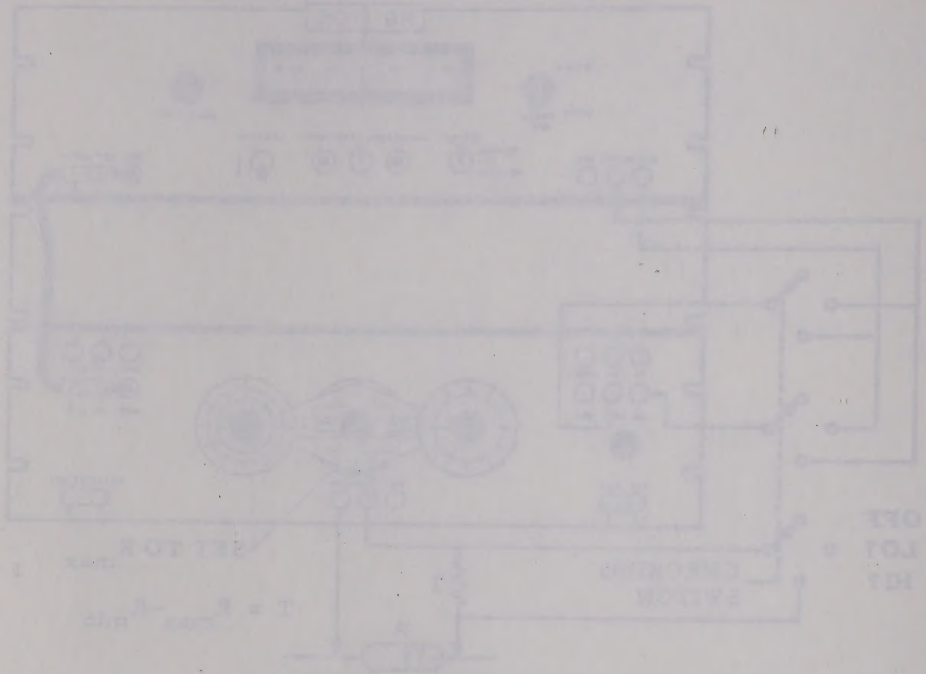
### 3.2.4 RESISTANCE LIMITS CHECKING *the esi way*

For rapidly checking resistance values between two tolerance limits.




#### 3.2.4.1 BASIC INSTRUCTIONS

| | |
|---|---|
| SET THE CIRCUIT SELECTOR TO R OR G. SET THE RANGE SWITCH AND MAIN DIAL DEKASTAT® TO THE UPPER RESISTANCE LIMIT. | These settings will allow checking both upper and lower limits. |
| CONNECT THE CIRCUIT AS SHOWN. | The generator reversal permits using the same direction of GALVANOMETER deflection for OK with both the upper and lower limit. |
| ATTACH THE PROBES TO THE UNKNOWN RESISTOR. | This completes the bridge circuit. |
| CHECK THE ZERO POSITION OF THE GALVANOMETER POINTER. | The zero position may be adjusted by the GALVANOMETER ZERO SET dial. |



3.2.4.1 RESISTANCE LIMITS CHECKING (Cont.)

| | |
|---|---|
| FIND THE OPTIMUM SENSITIVITY SETTING BY TRIAL. | The sensitivity buttons may be left in the lock position without endangering the GALVANOMETER. |
| SET THE CHECKING SWITCH TO "IS R LO?". | If the GALVANOMETER deflects to the right the unknown resistor is above the lower tolerance limit. |
| SET THE CHECKING SWITCH TO "IS R HI?". | If the GALVANOMETER deflects to the right the unknown resistor is below the upper tolerance limit. |

NOTE: If the resistance tolerance is given as $\pm\Delta\%$, the value of T will be $\frac{R2\Delta}{100}$ and $R_{max}$ will be $(1 + \frac{\Delta}{100})$ R.

3.2.4.2 CHECKING HIGH RESISTANCE:

When checking high resistances the 300 volt supply should be used. The off position of the checking switch has been provided to remove this voltage from the bridge while changing resistors.

3.2.4.3 CHECKING LOW RESISTANCE:

When checking low resistances the probe resistance $R_o$ must be taken into account. It can be measured by shorting the probes. The bridge dials should be set to read $R_{max} + R_o$.

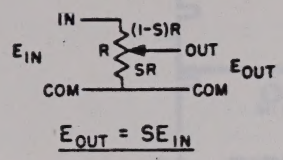
RESISTANCE LIMITS CHECKING

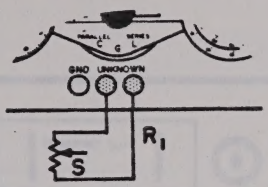
IF
$R_{MIN} < R < R_{MAX}$
AND IF
$T = R_{MAX} - R_{MIN}$
THEN
$(R_{MEAS}) < R_{MAX}$ Only if $R < R_{MAX}$
$(R_{MEAS} + T) > R_{MAX}$ Only if $R > R_{MIN}$

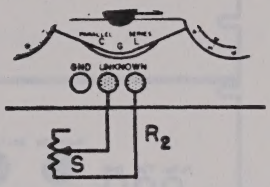
IF
$R(1+\Delta) = R_{MAX}$
$R(1-\Delta) = R_{MIN}$
THEN
$T = R2\Delta$

## 3.2.5 VOLTAGE DIVIDER CHECKING *the esi way*

### 3.2.5.1 SIMPLE TAPPED RESISTOR



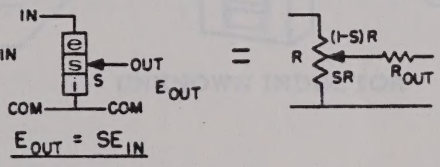



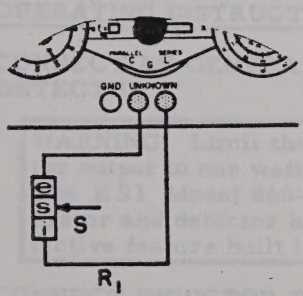



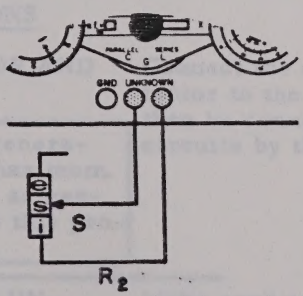

1. Follow the instructions for RESISTANCE measurement (3.2).
2. Measure $R_1$ between the input and common terminals.
3. Measure $R_2$ between the output and common terminals.
4. Calculate the divider setting S.

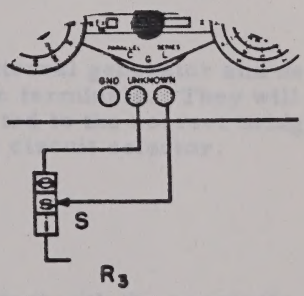
$$S = \frac{R_2}{R_1}$$

### 3.2.5.2 KELVIN VARLEY and other voltage divider types which may have equivalent resistance in the output lead.



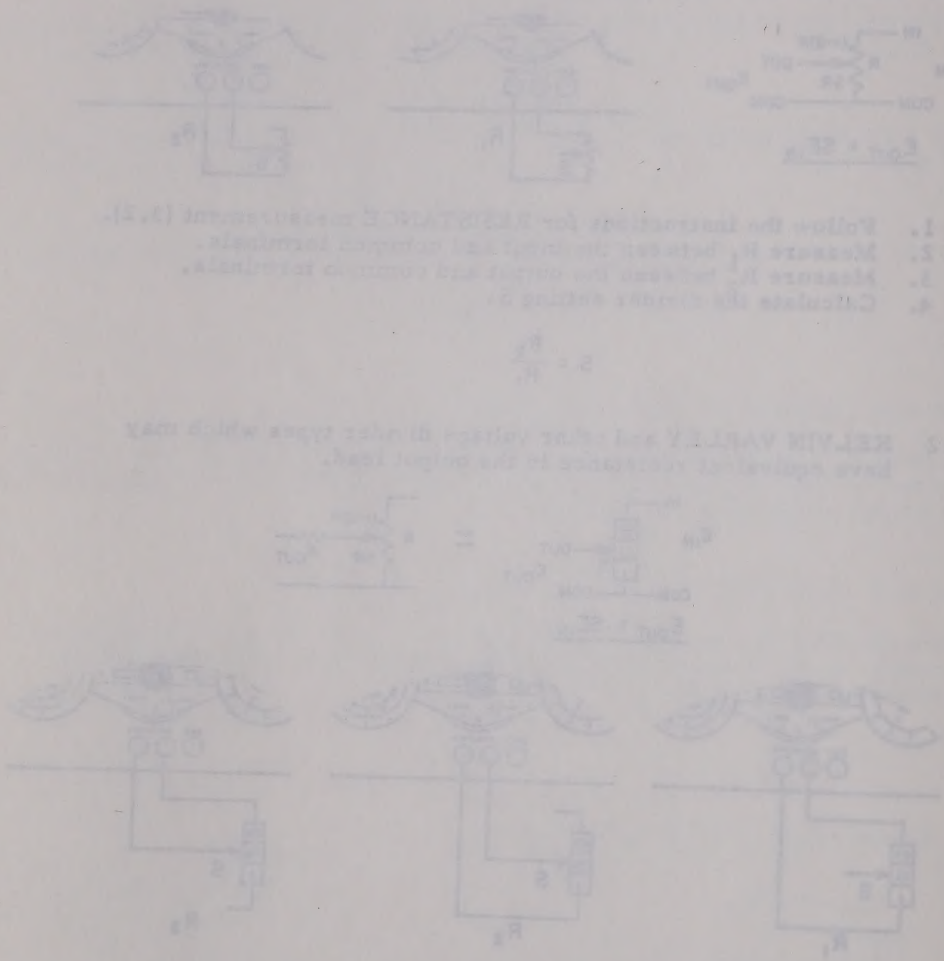



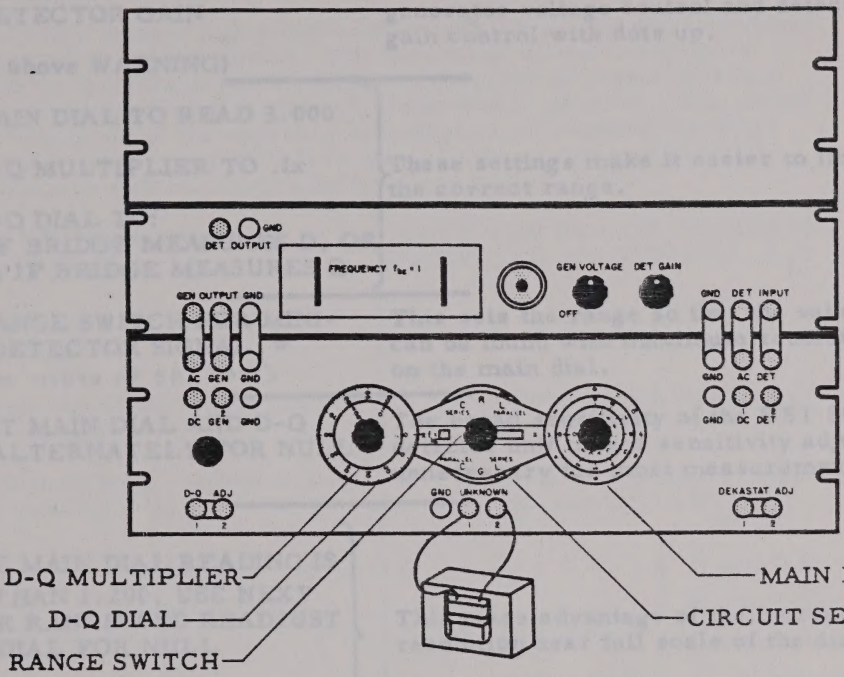

1. Follow the instructions for RESISTANCE measurement (3.2)
2. Measure $R_1$ between the input and common terminals.
3. Measure $R_2$ between the output and common terminals.
4. Measure $R_3$ between the input and output terminals.
5. Calculate the divider setting S.

$$S = \frac{1}{2} + \frac{R_2 - R_3}{2R_1}$$



## 3.3 INDUCTORS

### 3.3.1 MEASURING INDUCTORS *the esi way*




## OPERATING INSTRUCTIONS

**CONNECT AC GENERATOR AND DETECTOR**

Connect the external generator and detector to the ac terminals. They will then be connected to the correct bridge circuits by the circuit selector.

> WARNING: Limit the generator output to one watt maximum. The ESI Model 860-R ac generator and detector has this protective feature built in.

**CONNECT INDUCTOR TO UNKNOWN TERMINALS**

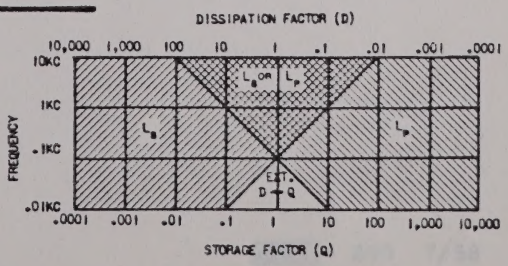
Make good contact with the terminals.

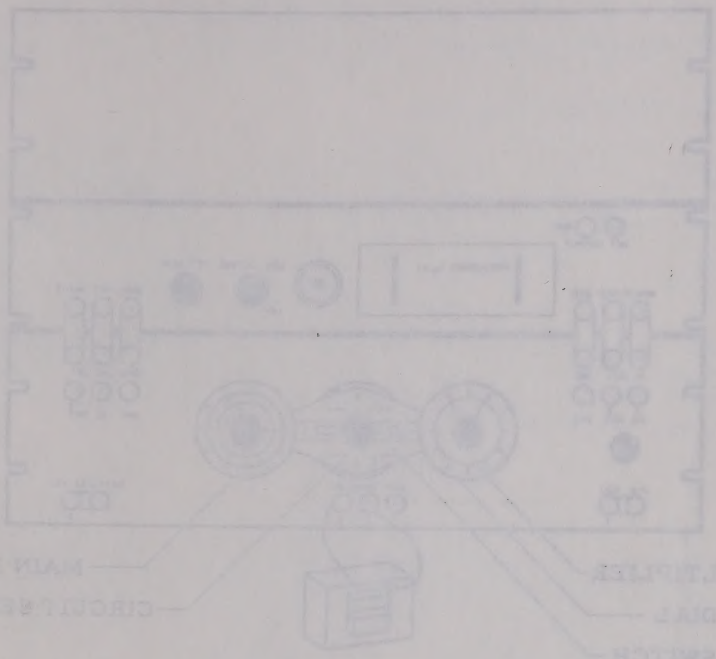
**SET CIRCUIT SELECTOR TO $L_p$ OR $L_s$**

At 1 kc:

Use $L_p$ for Q greater than 0.1

Use $L_s$ for Q lower than 10





| | |
|---|---|
| SET GENERATOR VOLTAGE AND DETECTOR GAIN<br>(See above WARNING) | For 860-R generator-detector unit, set generator voltage control and detector gain control with dots up. |
| SET MAIN DIAL TO READ 3.000<br>SET D-Q MULTIPLIER TO .1x<br>SET D-Q DIAL TO:<br>0, IF BRIDGE MEASURES D, OR<br>100, IF BRIDGE MEASURES Q | These settings make it easier to find the correct range. |
| SET RANGE SWITCH FOR MINIMUM DETECTOR SIGNAL *<br>(MAXIMUM WIDTH OF SHADOW) | This sets the range so that the value can be found with maximum resolution on the main dial. |
| ADJUST MAIN DIAL AND D-Q DIAL ALTERNATELY FOR NULL | The broad sensitivity of the ESI 860-R detector unit makes sensitivity adjustment unnecessary for most measurements. |
| IF THE MAIN DIAL READING IS LESS THAN 1.200, USE NEXT LOWER RANGE AND READJUST MAIN DIAL FOR NULL<br>IF D-Q DIAL READING IS LESS THAN 10, USE NEXT LOWER SETTING OF D-Q MULTIPLIER AND READJUST D-Q DIAL FOR NULL | This takes advantage of the increased resolution near full scale of the dials. |

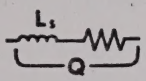
* Use oscilloscope as detector. Connect it to detector output, on left side of 860-R. Adjust main dial on 290-R for minimum pattern on scope.

SEE NEXT PAGE

### 3.3.2 SERIES AND PARALLEL INDUCTANCE

The bridge measures a simple equivalent circuit for the impedance connected to its terminals. This equivalent circuit consists of either an inductance and resistance connected in series or a different inductance and resistance connected in parallel. The phase and magnitude of the resulting impedance are identical for both circuits. For values of Q less than 100 the series and parallel inductances differ measurably (by more than 0.01%).

**WHEN THE BRIDGE MEASURES SERIES INDUCTANCE, $L_s$:**




$L_s$ = (range switch setting) x (main dial reading)

$Q$ = (D-Q multiplier setting) x (D-Q dial reading) x ($f_{kc}$)

$D = \frac{1}{Q}$

$R_s = \frac{1}{Q} \times 2\pi f L_s$

$Z = 2\pi f L_s (\frac{1}{Q} + j)$

Q and D in per unit
$R_s$ in kilohms
f in kc
$L_s$ in henrys
$j = \sqrt{-1}$
Z in kilohms

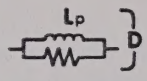
To calculate the equivalent parallel circuit:

The Q of the equivalent parallel circuit always equals the Q of the equivalent series circuit. The same is true of D.

$L_p = (1 + \frac{1}{Q^2}) \times L_s$

$R_p = Q \times 2\pi f L_p$

**WHEN THE BRIDGE MEASURES PARALLEL INDUCTANCE, $L_p$:**




$L_p$ = (range switch setting) x (main dial reading)

$D$ = (D-Q multiplier setting) x (D-Q dial reading) x ($f_{kc}$)

$Q = \frac{1}{D}$

$R_p = \frac{1}{D} \times 2\pi f L_p$

$Z = \frac{2\pi f L_p (D+j)}{D^2 + 1}$

D and Q in per unit
$R_p$ in kilohms
f in kc
$L_p$ in henrys
$j = \sqrt{-1}$
Z in kilohms

To calculate the equivalent series circuit:

The D of the equivalent series circuit always equals the D of the equivalent parallel circuit. The same is true of Q.

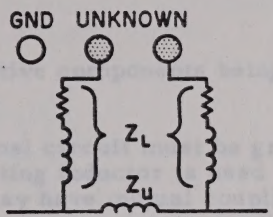
$L_s = \frac{1}{1 + D^2} \times L_p$

$R_s = D \times 2\pi f L_s$

### 3.3.3 THINGS TO WATCH OUT FOR

#### 3.3.3.1 LOW INDUCTANCE MEASUREMENTS

The bridge measures the total impedance connected to its terminals. Both the unknown inductor and its leads contribute to this impedance. The leads have some resistance and inductance, which affect the value read from the bridge.




$$Z_{measured} = Z_u + Z_L$$

$Z_u$ - Impedance of unknown inductor

$Z_L$ - Impedance of leads

For greatest accuracy, minimize the lead impedance. Short heavy leads will reduce the resistance. Closely spaced twisted leads will reduce the inductance and the pickup of stray fields.

#### 3.3.3.2 HIGH INDUCTANCE MEASUREMENTS

In making high inductance measurements, there are two things to watch out for:

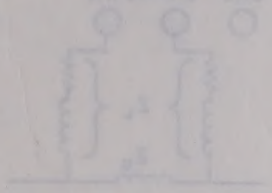
1. Be careful to avoid hum pickup.
2. Keep the stray capacitance to a minimum.

To minimize both effects keep your hands as far as possible from the inductor measured.

Keep the leads as short and direct as possible. If extended leads are necessary, the lead from the center terminal should be shielded. See section 3.4.6 "Extended Leads".

Care should be taken to avoid coupling stray magnetic fields into the inductor being measured.

The D and Q readings on the highest L range will be in error as indicated in the specifications because of the residual capacitance of the range resistor. If accurate D or Q readings are needed the next lowest L range can be used. The L readings on the high range are accurate.



### 3.3.4 INDUCTANCE MEASUREMENTS WITH DC

#### 3.3.4.1 WHEN TO USE DC

Iron core inductors are sensitive to both ac and dc current variations. Quantitative measurements of these effects can be made with the bridge.

#### 3.3.4.2 THINGS TO WATCH OUT FOR

A. GENERAL PRECAUTIONS

Stray ac pickup may change sensitive components being measured or may give erroneous null detector readings.

The ac impedance of the dc external circuit must be greater than 2000 ohms for maximum sensitivity. If an isolating inductor is used to raise the ac impedance it may pick up stray signals or may have mutual coupling with the unknown inductor being measured. Either one may cause reading errors. Such an inductor should be well shielded magnetically and be placed to minimize its chance of interfering. For low currents isolation may be accomplished with a resistor instead of the inductor.

The parallel inductance circuit is recommended because it simplifies dc current measuring and bridge protection problems. With the series circuit the dc current divides between the bridge arms so that it is difficult to meter. The series circuit would also require a more careful analysis to avoid excessive current in any of the bridge arms.

If equivalent series inductance is required it can be easily calculated from the parallel inductance and D (See Sec. 3.3.2).

If D is too high to be read directly, an external rheostat such as the ESI Model DB-655 DEKASTAT®, connected to the D-Q ADJ terminals can be used to extend the D range. If the parallel inductance circuit is used D can be calculated by the equation:

$$D = D_{reading} + 0.628\, R_{k\Omega}\, f_{kc}$$

where:

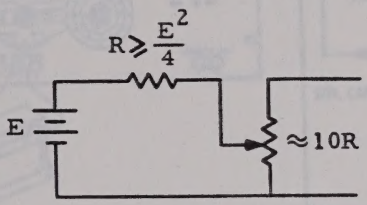
| | | |
|---|---|---|
| $D$ | - | Dissipation factor of unknown inductor |
| $D_{reading}$ | - | D reading of bridge (Multiplier x dial reading x $f_{kc}$) |
| $R_{k\Omega}$ | - | External rheostat resistance in kilohms |
| $f_{kc}$ | - | Operating frequency in kilocycles |

B. WITH DC SUPPLIED THROUGH THE GENERATOR TERMINALS

Supplying the dc signal through the generator terminals allows more current for measuring inductors below 1.2 millihenrys. With this connection the dc current is not affected by balancing the bridge. A grounded dc generator cannot be used

because one of the detector terminals is grounded. Leakage capacitance and resistance from the dc source to ground will be across bridge arms and may cause significant errors.

Most line operated dc power supplies have high leakage capacitance to the ac line and enough dc leakage to be objectionable. An insulated, isolated battery is the recommended power supply. If a variable supply is needed the circuit shown below can be used. This circuit has a maximum output of one watt so it will not exceed the rating of any bridge element.




With the parallel inductance circuit the standard capacitor blocks the dc from all of the bridge arms except the inductor being measured and the range resistor. As a result the maximum allowable current will be limited by the range resistor. This current limit is shown in Section 3.3.4.3.

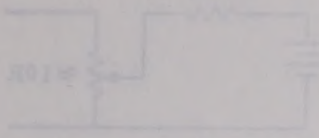
C. WITH DC SUPPLIED THROUGH THE DETECTOR TERMINALS

Supplying the dc signal through the detector terminals allows the use of higher current in measuring inductors above 1.2 millihenrys but the dc current will be influenced by the main dial DEKASTAT setting.

Since one of the detector terminals is normally grounded in the 860-R AC GENERATOR-DETECTOR a grounded power supply can be used.

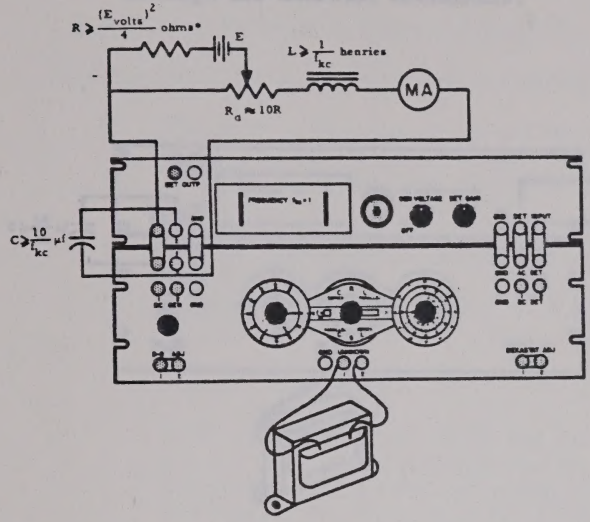
The problems resulting from stray ac pickup either from the ripple of a dc supply, capacitive coupling to power lines or the bridge generator, stray field pickup by the isolating inductor (if used), or inductive coupling to the unknown inductor, are much more serious with this connection because of the direct coupling to the detector.

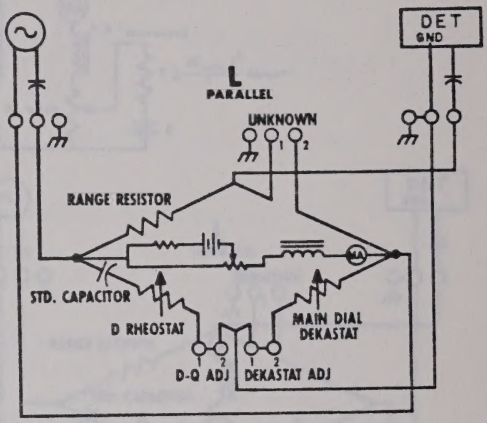
In this circuit the current goes through the unknown inductor and the main dial DEKASTAT. It must be limited by the values given in Section 3.3.4.4. If more current is needed the range can be increased by one setting and the first DEKASTAT dial turned to zero. This will decrease the DEKASTAT resistance and increase its current rating. Because of the high resolution of the main dial DEKASTAT accurate measurements are possible even when the first dial is not used. By setting the first two dials to zero higher current is possible but only 100 divisions of resolution are left.



## 3.3.4 INDUCTANCE MEASUREMENT WITH DC (cont'd.)

### 3.3.4.3 For parallel inductance measurement with dc superimposed through the generator terminals.




CONNECT AS SHOWN

| | |
|---|---|
| E - VOLTAGE SOURCE | The detector input should have an isolating capacitor. This capacitor is built into the Model 860-R Generator-Detector. |
| R - POWER LIMITING RESISTOR | Protects the bridge, detector and unknown inductor. |
| L - ISOLATING INDUCTOR | Avoid ac pickup and coupling to the unknown. Prevents excessive generator loading. Not necessary if R$\geq$100 ohms. |
| C - ISOLATING CAPACITOR | Keeps dc out of the Generator. |
| $R_d$ - CURRENT ADJUSTING CONTROL | To set desired current. |
| MA - CURRENT MONITORING METER | To measure dc current. |

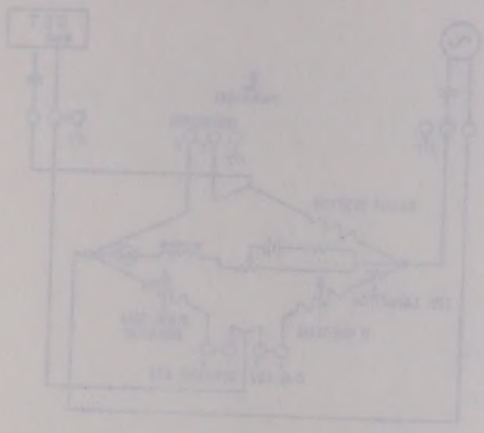
ADJUST THE DC CURRENT AS REQUIRED

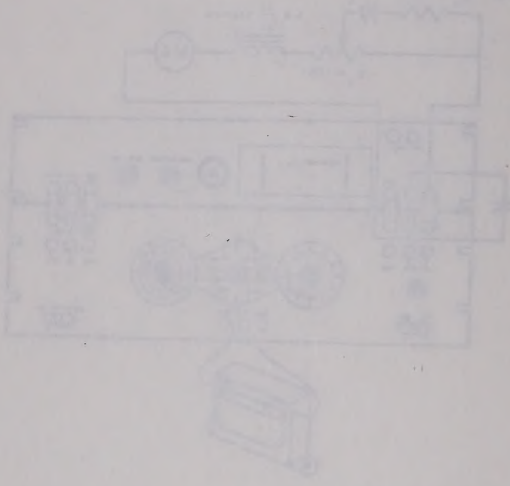
MEASURE THE INDUCTANCE — See Section 3.3

*This limits to one watt the dc power which can be supplied to the bridge thus protecting all of the bridge circuit. With care more current and voltage can be applied. The current rating of the bridge is given in the table below. These values should never be exceeded.

| RANGE | UNKNOWN INDUCTANCE** | MAXIMUM CURRENT |
|---|---|---|
| $10^{-4}$ | 0.1 µh to 1.2 mh | 710 ma |
| $10^{-3}$ | 1 µh to 12 mh | 230 ma |
| $10^{-2}$ | 10 µh to 120 mh | 71 ma |
| $10^{-1}$ | 100 µh to 1.2 h | 23 ma |
| 1 | 1 mh to 12 h | 7.1 ma |
| 10 | 10 mh to 120 h | 2.3 ma |
| 100 | 100 mh to 1200 h | 250 µa |

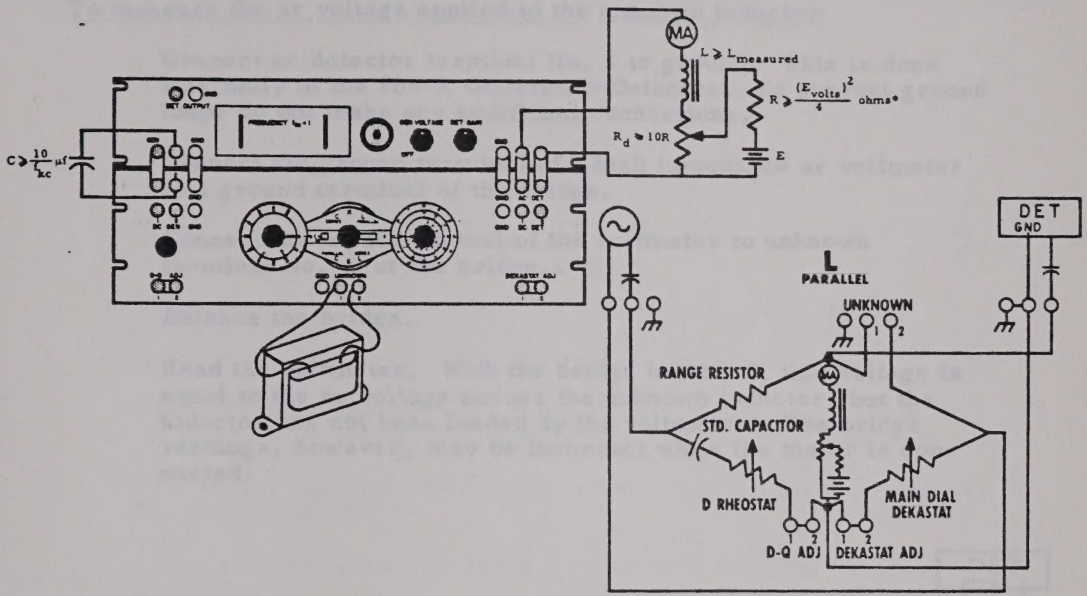
**Lower limit is one dial division





## 3.3.4 INDUCTANCE MEASUREMENT WITH DC (cont'd.)

### 3.3.4.4 For parallel inductance measurements with dc superimposed through the detector terminals.



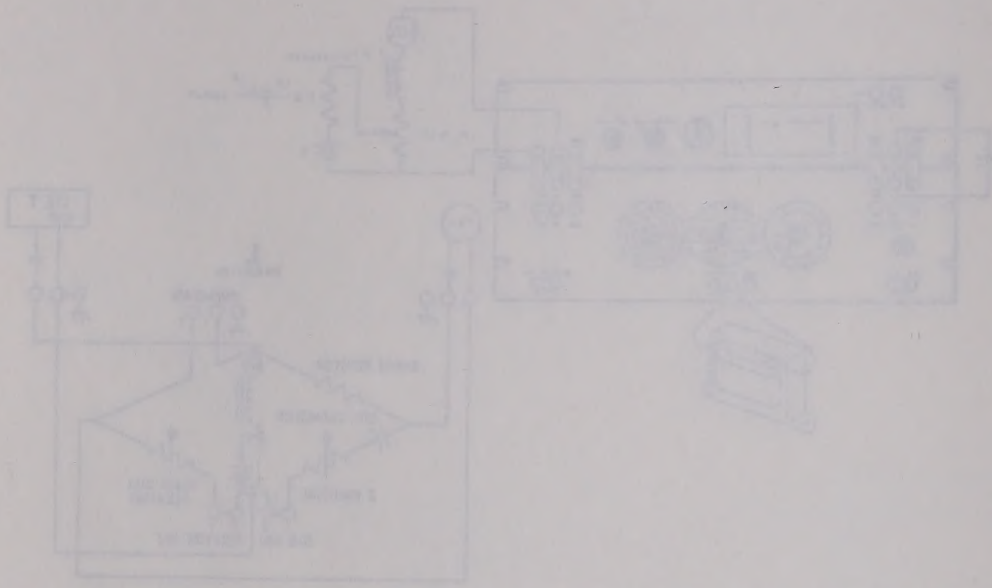

CONNECT AS SHOWN

| | |
|---|---|
| E - VOLTAGE SOURCE | The detector input should have an isolating capacitor. This capacitor is built into the Model 860-R Generator - Detector. |
| R - POWER LIMITING RESISTOR | Protects bridge, detector and unknown inductor. |
| L - ISOLATING INDUCTOR | Avoid ac pickup and coupling to the unknown. Prevents excessive generator loading. Not necessary if $R \geq (L_{h\text{-measured}})(f_{kc})(6)$ kilohms. |
| C - ISOLATING CAPACITOR | Keeps dc out of the Generator |
| $R_d$ - CURRENT ADJUSTING CONTROL | To set desired current. |
| MA - CURRENT MONITORING METER | To measure dc current. |
| ADJUST THE DC CURRENT AS REQUIRED | The current will vary with the setting of the main dial. |
| MEASURE THE INDUCTANCE | See Section 3.3 |

*This limits to one watt the dc power which can be supplied to the bridge thus protecting all of the bridge circuit. With care more current and voltage can be applied. The current rating of the bridge is given in the table below. The outer dial must be set to zero to use the "MIDDLE" dial rating. Both outer dials must be set to zero to use the "POT" dial rating. These values should never be exceeded.

| RESOLUTION | DIAL | UNKNOWN INDUCTANCE** | MAXIMUM CURRENT |
|---|---|---|---|
| 12,005 div | OUTER | 100.0 μh to 1200 h | 23 ma |
| 1,005 div | MIDDLE | 10.0 μh to 100 h | 71 ma |
| 105 div | POT | 0.1 μh to 10.5 h | 270 ma |

**Lower limit is one division on dial which limits current on lowest range.



### 3.3.5 AC VOLTAGE MEASUREMENT

To measure the ac voltage applied to the unknown inductor:

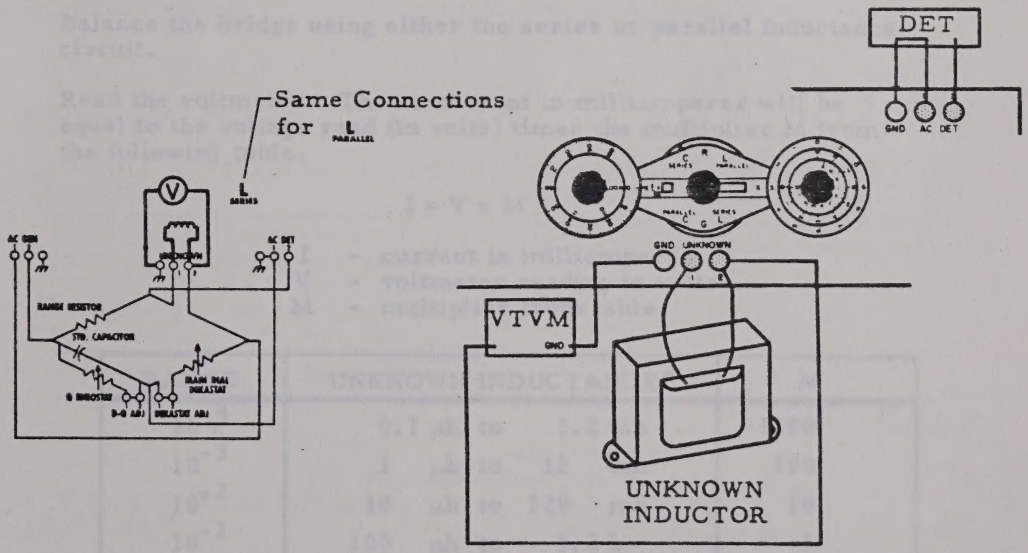
Connect ac detector terminal No. 1 to ground. This is done internally in the 860-R Generator-Detector. To prevent ground loops do not make any additional connections.

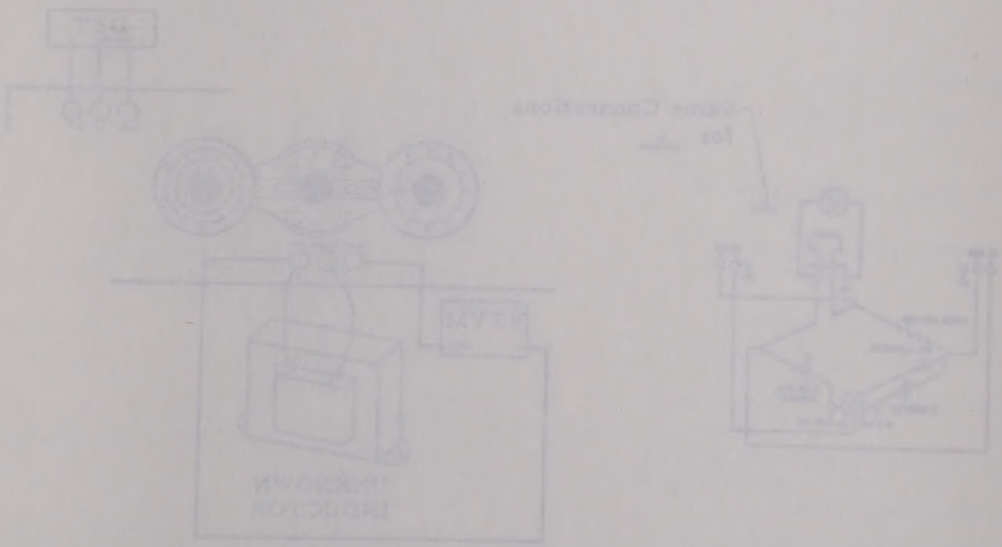
Connect the ground terminal of a high impedance ac voltmeter to a ground terminal of the bridge.

Connect the input terminal of the voltmeter to unknown terminal No. 2 of the bridge..

Balance the bridge.

Read the voltmeter. With the bridge balanced, this voltage is equal to the ac voltage across the unknown inductor, but the inductor has not been loaded by the voltmeter. The bridge readings, however, may be incorrect while the meter is connected.

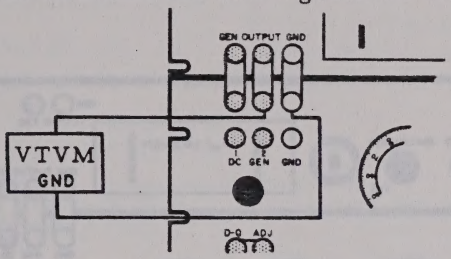




### 3.3.6 AC CURRENT MEASUREMENT

To measure the ac current supplied to the unknown inductor:

The ac voltage across the range resistor is proportional to the ac current through the unknown. At balance this voltage is equal to the voltage across the standard capacitor arm which can be measured with a grounded voltmeter.




Connect ac detector terminal No. 1 to ground. This is done internally in the 860-R Generator-Detector. To prevent ground loops do not make any additional connections.

Connect the ground terminal of a high impedance sensitive ac vacuum tube voltmeter to the ground terminal of the bridge.

Connect the input terminal of the voltmeter to AC GEN terminal No. 2 of the bridge.

Balance the bridge using either the series or parallel inductance circuit.

Read the voltmeter. The ac current in milliamperes will be equal to the voltage read (in volts) times the multiplier M from the following table.

$$I = V \times M$$

I - current in milliamperes
V - voltmeter reading in volts
M - multiplier from table

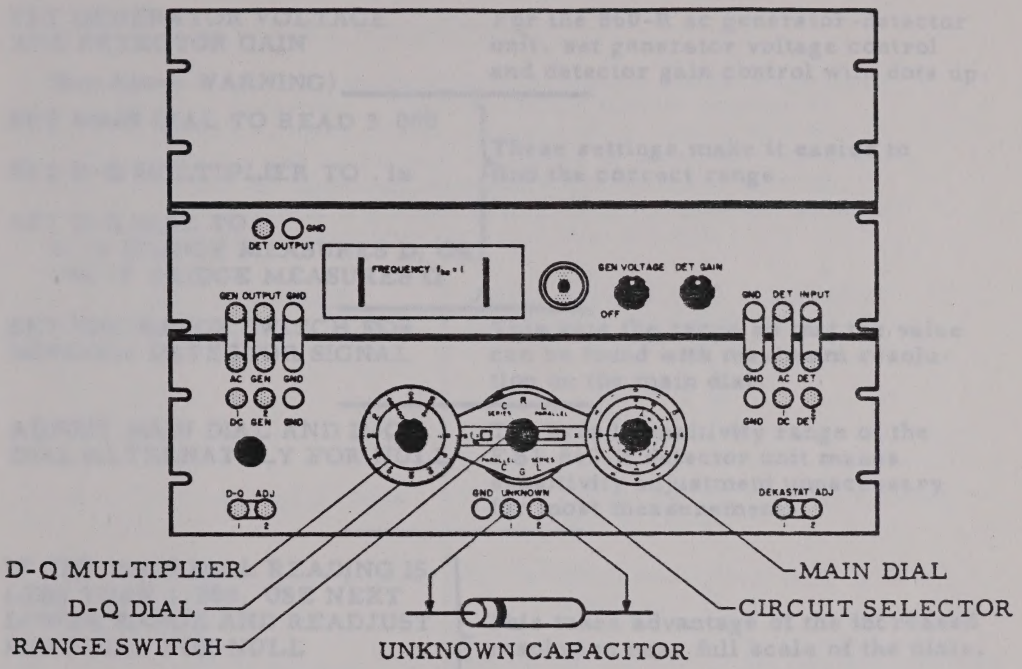
| RANGE | UNKNOWN INDUCTANCE* | M |
|---|---|---|
| $10^{-4}$ | 0.1 μh to 1.2 mh | 1000 |
| $10^{-3}$ | 1 μh to 12 mh | 100 |
| $10^{-2}$ | 10 μh to 120 mh | 10 |
| $10^{-1}$ | 100 μh to 1.2 h | 1 |
| 1 | 1 mh to 12 h | 0.1 |
| 10 | 10 mh to 120 h | 0.01 |
| 100 | 100 mh to 1200 h | 0.001 |

*Lower limit represents one dial division.

Remove the voltmeter and re-balance the bridge for the precise inductance measurement.

## 3.4 CAPACITORS

### 3.4.1 MEASURING CAPACITORS the esi way




OPERATING INSTRUCTIONS

CONNECT AC GENERATOR AND DETECTOR

WARNING: Limit the generator output to one watt maximum. The ESI Model 860-R ac generator and detector has this protective feature built in.

Connect the external generator and detector to the ac terminals. They will then be connected to the correct bridge circuits by the circuit selector.

CONNECT CAPACITOR TO UNKNOWN TERMINALS

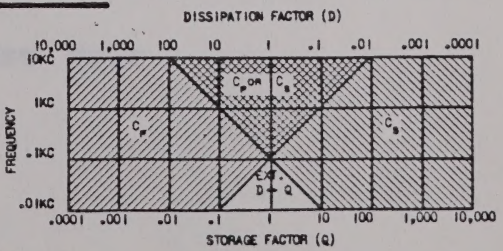
To minimize stray capacitance to ground, connect the outside foil to the left hand terminal.

SET THE CIRCUIT SELECTOR TO $C_s$ OR $C_p$

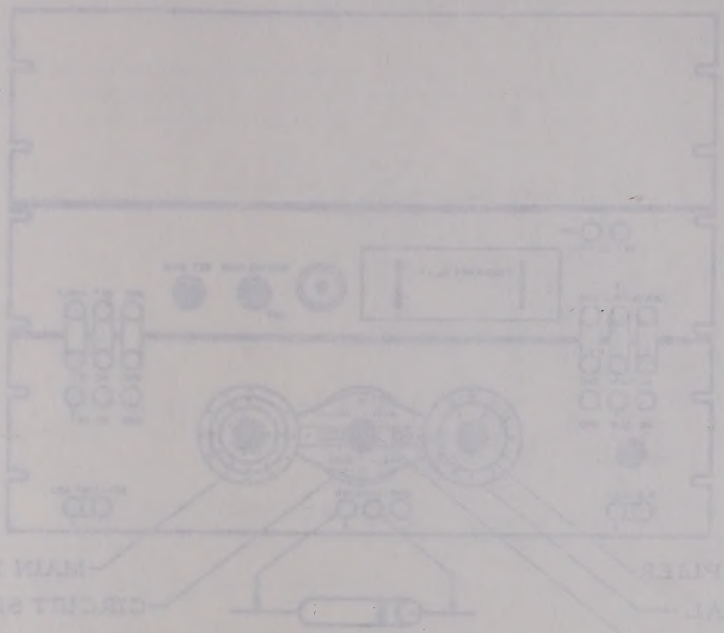
At 1 kc:

Use $C_p$ for D greater than 0.1

Use $C_s$ for D lower than 10




Range of D and Q covered by $C_s$ and $C_p$ circuits.



## 3.4.1 MEASURING CAPACITORS (Cont.)

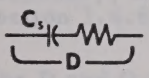
| | |
|---|---|
| SET GENERATOR VOLTAGE AND DETECTOR GAIN<br>(See Above WARNING) | For the 860-R ac generator-detector unit, set generator voltage control and detector gain control with dots up. |
| SET MAIN DIAL TO READ 3.000<br><br>SET D-Q MULTIPLIER TO .1x<br><br>SET D-Q DIAL TO<br>0, IF BRIDGE MEASURES D, OR<br>100, IF BRIDGE MEASURES Q | These settings make it easier to find the correct range. |
| SET THE RANGE SWITCH FOR MINIMUM DETECTOR SIGNAL | This sets the range so that the value can be found with maximum resolution on the main dial. |
| ADJUST MAIN DIAL AND D-Q DIAL ALTERNATELY FOR NULL | The broad sensitivity range of the ESI 860-R detector unit makes sensitivity adjustment unnecessary for most measurements. |
| IF THE MAIN DIAL READING IS LESS THAN 1.200, USE NEXT LOWER RANGE AND READJUST MAIN DIAL FOR NULL<br><br>IF D-Q DIAL READING IS LESS THAN 10, USE NEXT LOWER SETTING OF D-Q MULTIPLIER AND READJUST D-Q DIAL FOR NULL | This takes advantage of the increased resolution near full scale of the dials. |

SEE NEXT PAGE

## 3.4.2 SERIES AND PARALLEL CAPACITANCE

The bridge measures a simple equivalent circuit for the impedance connected to its terminals. This equivalent circuit consists of either a capacitance and resistance connected in series or a different capacitance and resistance connected in parallel. The phase and magnitude of the resulting impedance are identical for both circuits. For values of D greater than 0.01 the series and parallel capacitances differ measurably (by more than 0.01%).

### WHEN THE BRIDGE MEASURES SERIES CAPACITANCE, $C_s$:




$C_s$ = (range switch setting) x (main dial reading)

D = (D-Q multiplier setting) x (D-Q dial reading) x ($f_{kc}$)

$Q = \frac{1}{D}$

$R_s = \frac{D}{2\pi f C_s}$

$Z = \frac{D - j}{2\pi f C_s}$

D and Q in per unit
$R_s$ in kilohms
f in kc
$C_s$ in microfarads
$j = \sqrt{-1}$
Z in kilohms

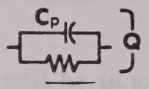
To calculate the equivalent parallel circuit:

The D of the equivalent parallel circuit always equals the D of the equivalent series circuit. The same is true of Q.

$C_p = \frac{C_s}{(1 + D^2)}$

$R_p = \frac{1}{D} \times \frac{1}{2\pi f C_p}$

### WHEN THE BRIDGE MEASURES PARALLEL CAPACITANCE, $C_p$:




$C_p$ = (range switch setting) x (main dial reading)

Q = (D-Q multiplier) x (D-Q dial reading) x ($f_{kc}$)

$D = \frac{1}{Q}$

$R_p = \frac{Q}{2\pi f C_p}$

$Z = \frac{\frac{1}{Q} - j}{2\pi f C_p (1 + \frac{1}{Q^2})}$

Q and D in per unit
$R_p$ in kilohms
f in kc
$C_p$ in microfarads
$j = \sqrt{-1}$
Z in kilohms

To calculate the equivalent series circuit:

The Q of the equivalent series circuit always equals the Q of the equivalent parallel circuit. The same is true of D.

$C_s = (1 + \frac{1}{Q^2}) \times C_p$

$R_s = \frac{1}{Q} \times \frac{1}{2\pi f C_s}$

### 3.4.3 THINGS TO WATCH OUT FOR

#### 3.4.3.1 LOW CAPACITANCE MEASUREMENTS

In making low capacitance measurements, there are two things to watch out for:

1. Be careful to avoid hum pickup.
2. Keep the stray capacitance to a minimum.

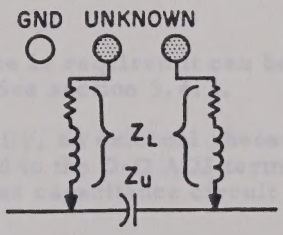
To minimize both effects, keep your hands as far as possible from the capacitor being measured.

Keep the leads as short and direct as possible. If extended leads are necessary, the lead from the center terminal should be shielded. See section 3.4.6, "Extended Leads."

The D and Q readings on the lowest C range will be in error as indicated in the specifications because of the residual capacitance of the range resistor. If accurate D or Q readings are needed the next highest C range can be used. The C readings on the low range are accurate.

#### 3.4.3.2 HIGH CAPACITANCE MEASUREMENTS

The bridge measures the total impedance connected to its terminals. Both the unknown capacitor and its leads contribute to this impedance. The leads have some resistance and inductance, which affect the value read from the bridge.




$$Z_{measured} = Z_u + Z_L$$

$Z_u$ = Impedance of unknown capacitor

$Z_L$ = Impedance of leads

For the greatest accuracy, minimize the lead impedance. Short heavy leads will reduce the resistance. Closely spaced twisted leads will reduce the inductance and the pickup of stray fields.

### 3.4.4 CAPACITANCE MEASUREMENT WITH DC

#### 3.4.4.1 WHEN TO USE DC

Some capacitors need a polarizing voltage. For example, electrolytic and tantalytic capacitors can be damaged by the reverse polarity half-cycle of the test frequency. Even if the capacitors are not damaged, erroneous readings may result.

A polarizing voltage is not always needed in these measurements. If the ac voltage is kept at a very low value (typically below one-half volt), the capacitor will not be damaged, and the readings will be reasonably accurate.

Because of the high sensitivity of the Model 291 bridge, accurate measurements can be made with a very low oscillator voltage. When operating with a low oscillator voltage, be sure that the detector sensitivity is high.

#### 3.4.4.2 THINGS TO WATCH OUT FOR

Stray ac pickup may change sensitive components being measured or may give erroneous null detector readings.

The ac impedance of the external dc circuit must be less than 200 ohms for maximum sensitivity.

The series capacitance circuit is recommended because it simplifies dc voltage protection and measuring problems. With the parallel circuit the dc voltage divides between the bridge arms so that it is difficult to meter. This also requires a more careful analysis to avoid excessive voltage across any of the bridge arms.

If equivalent parallel capacitance is required it can be easily calculated from the series capacitance and D. See section 3.4.2.

If D is too high to be read directly, an external rheostat such as the ESI Model DB-655 DEKASTAT®, connected to the D-Q ADJ terminals can be used to extend the D range. If the series capacitance circuit is used D can be calculated by the equation:

$$D = D_{reading} + 0.628\, R_{k\Omega}\, f_{kc}$$

where:

| | | |
|---|---|---|
| $D$ | - | Dissipation factor of unknown capacitor |
| $D_{reading}$ | - | D Reading of bridge (Multiplier x dial reading x $f_{kc}$) |
| $R_{k\Omega}$ | - | External rheostat resistance in kilohms |
| $f_{kc}$ | - | Operating frequency in kilocycles |

3.4.4.2 THINGS TO WATCH OUT FOR (cont'd.)

If the equivalent series resistance of the capacitor being measured is much greater than the resistance of the range resistor most of the dc input voltage will appear across the unknown capacitor. If the dc resistance of the unknown capacitor is known the voltage across it will be shown by the following equation:

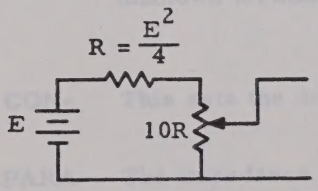
$$E_c = E_{in} \frac{R_c}{R_c + R_R}$$

where:

$E_c$ - DC voltage across the unknown capacitor
$E_{in}$ - DC voltage at the generator terminals
$R_c$ - DC resistance of the unknown capacitor
$R_R$ - Resistance of the range resistor

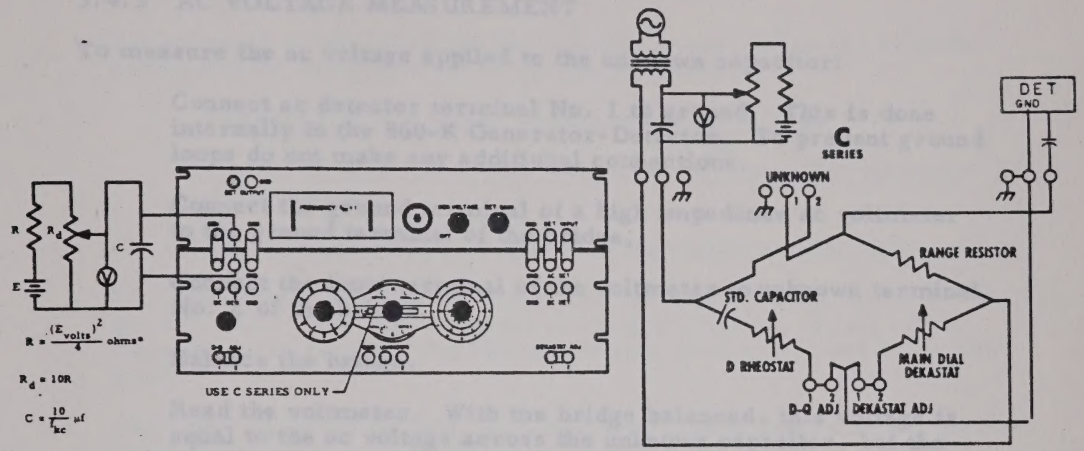
A grounded dc generator cannot be used because one of the detector terminals is grounded. Leakage capacitance and resistance from the dc source to ground will be across bridge arms and may cause significant errors.

Most line operated dc power supplies have high leakage capacitance to the ac line and enough dc leakage to be objectionable. An insulated isolated battery is the recommended power supply. If a variable supply is needed the circuit shown below can be used. This circuit has a maximum output of about one watt so it will not exceed the rating of any bridge element.



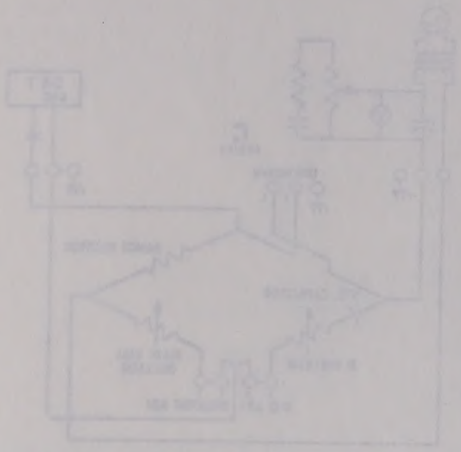

With the series inductance circuit the standard capacitor is subjected to the same dc voltage as the unknown capacitor. As a result the maximum allowable voltage must be limited to the standard capacitor rating of 300 volts.

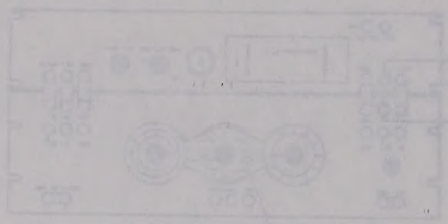
### 3.4.4.3 FOR SERIES CAPACITANCE MEASUREMENTS WITH SUPERIMPOSED DC:




| | |
|---|---|
| CONNECT THE CIRCUIT AS SHOWN | The detector input should have an isolating capacitor. This capacitor is built into the Model 860-R Generator-Detector. |
| E - DC VOLTAGE SOURCE | Battery recommended to avoid stray pickup and leakage |
| R - POWER LIMITING RESISTOR $R = \frac{(E_{volts})^2}{4}$ ohms* | This protects the bridge in case the unknown terminals are shorted. |
| $R_D$ - VOLTAGE ADJUSTING CONTROL | This sets the dc voltage. |
| CONNECT THE METER "V" IN PARALLEL WITH THE DC SUPPLY | The impedance of most meters is high enough so that they will not load the dc supply. |
| ADJUST THE DC VOLTAGE AS REQUIRED | For low leakage capacitors the voltage across the unknown capacitor will be equal to the voltmeter "V" reading. |
| MEASURE THE CAPACITANCE | See section 3.3.4. |

*This limits the dc power that can be supplied to the bridge to one watt to protect all of the bridge circuit in case the unknown capacitor is accidentally shorted. The maximum dc supply should not exceed 300 volts for the protection of the standard capacitor.





### 3.4.5 AC VOLTAGE MEASUREMENT

To measure the ac voltage applied to the unknown capacitor:

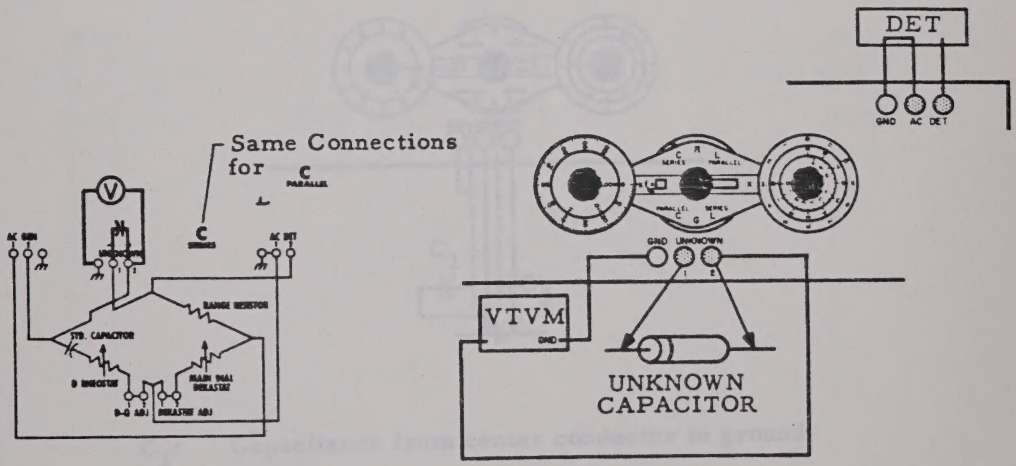
Connect ac detector terminal No. 1 to ground. This is done internally in the 860-R Generator-Detector. To prevent ground loops do not make any additional connections.

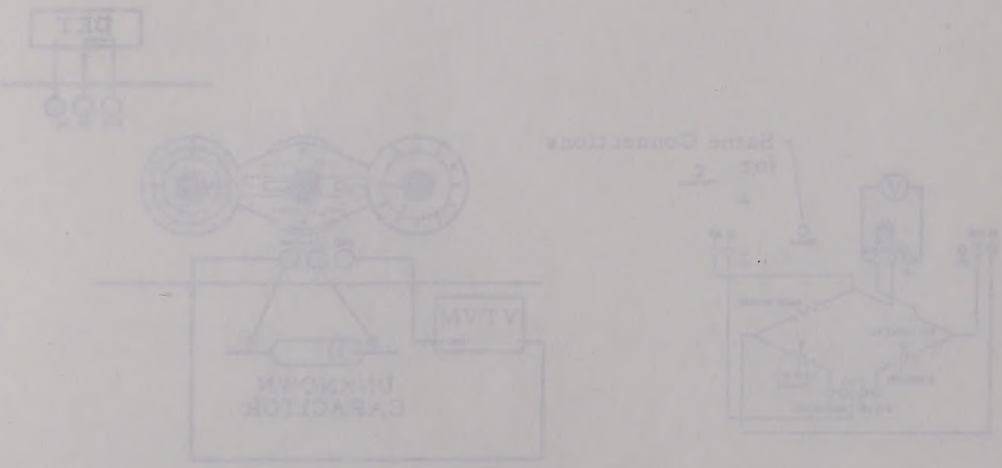
Connect the ground terminal of a high impedance ac voltmeter to the ground terminal of the bridge.

Connect the input terminal of the voltmeter to unknown terminal No. 2 of the bridge.

Balance the bridge.

Read the voltmeter. With the bridge balanced, this voltage is equal to the ac voltage across the unknown capacitor, but the capacitor has not been loaded by the voltmeter. The bridge readings, however, may be incorrect while the meter is connected.





### 3.4.6 EXTENDED LEADS

Sometimes it is necessary to use extended leads. This can be done easily without causing error in the measurement.

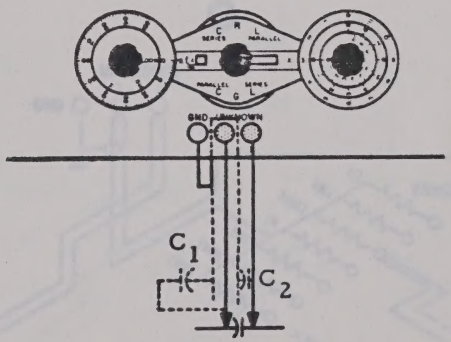
Connect a shielded lead to unknown terminal No. 1.

Connect the shield of this lead to the adjacent GND terminal of the bridge.

Connect an ordinary clip lead to the right-hand terminal.

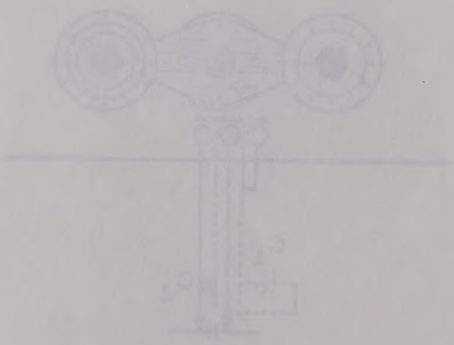
The capacitance between the shield and the center conductor is now across the detector. This keeps it from causing any error. If this stray capacitance is greater than 500 μμf, it may reduce the detector sensitivity.

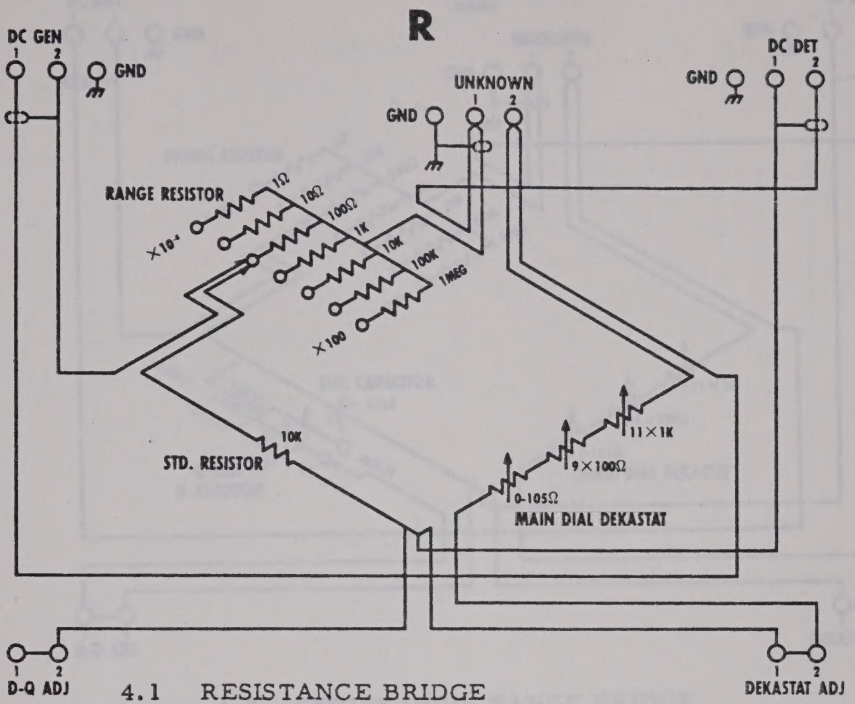
The stray capacitance from the unshielded lead to ground is across the standard capacitance arm of the bridge. As the standard capacitor is 100,000 μμf, the stray capacitance will not cause significant errors unless it exceeds a few 10's of μμf.



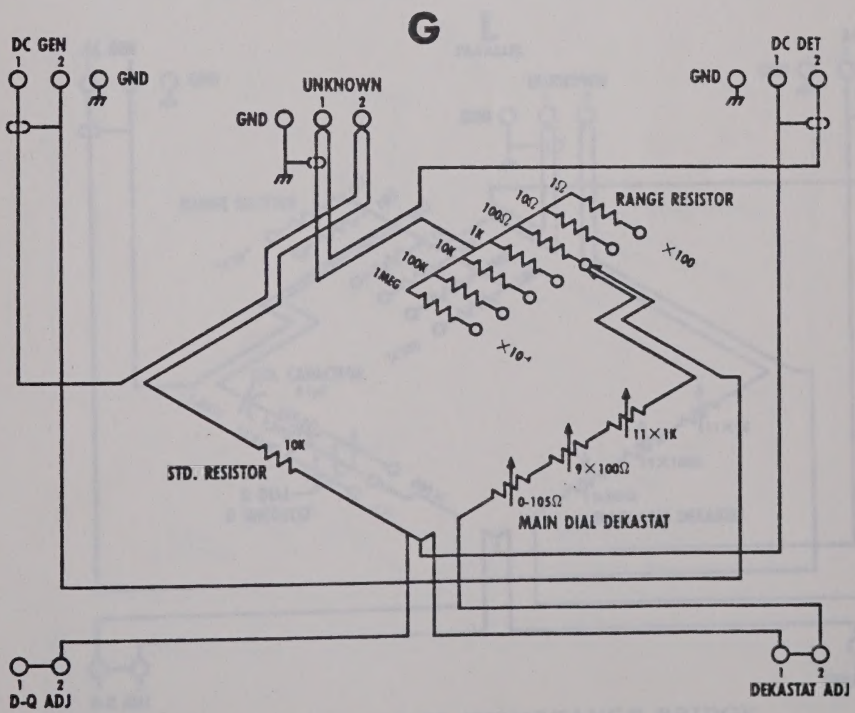

$C_1$: Capacitance from center conductor to ground

$C_2$: Capacitance from unshielded conductor to ground

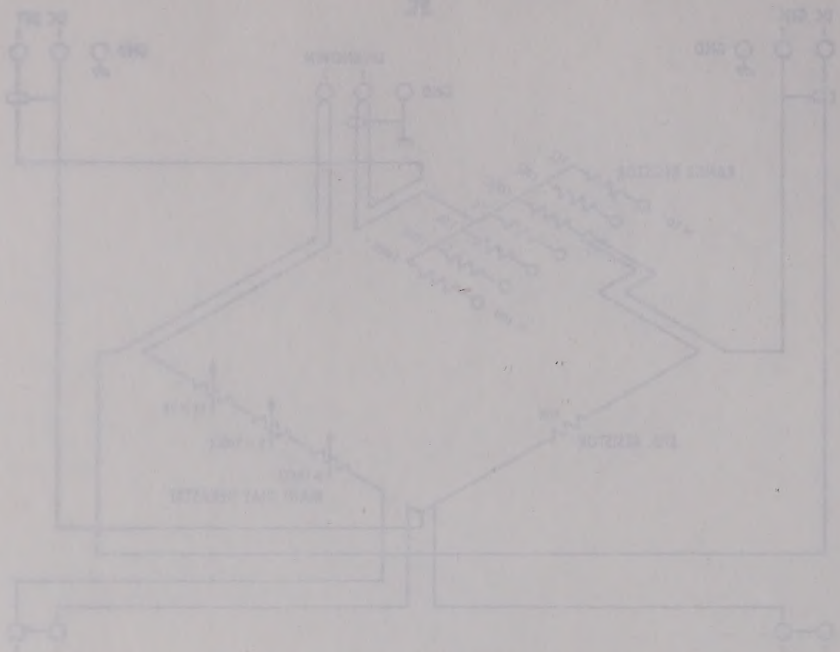


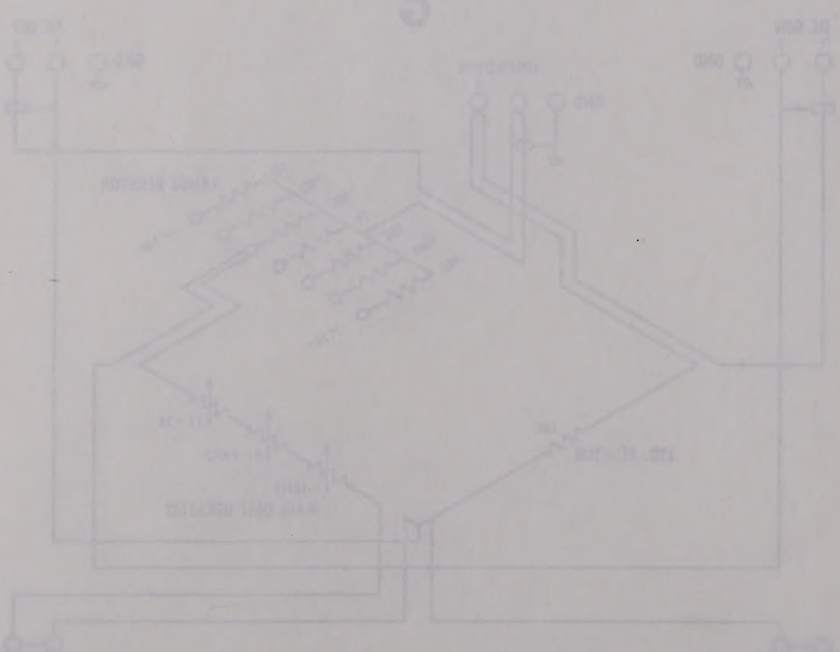


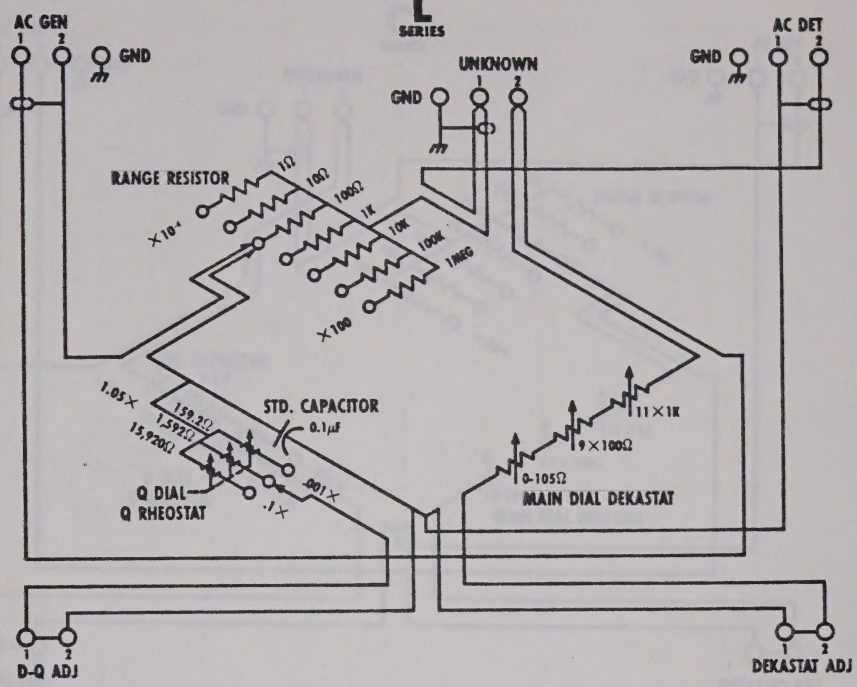

4.1 RESISTANCE BRIDGE



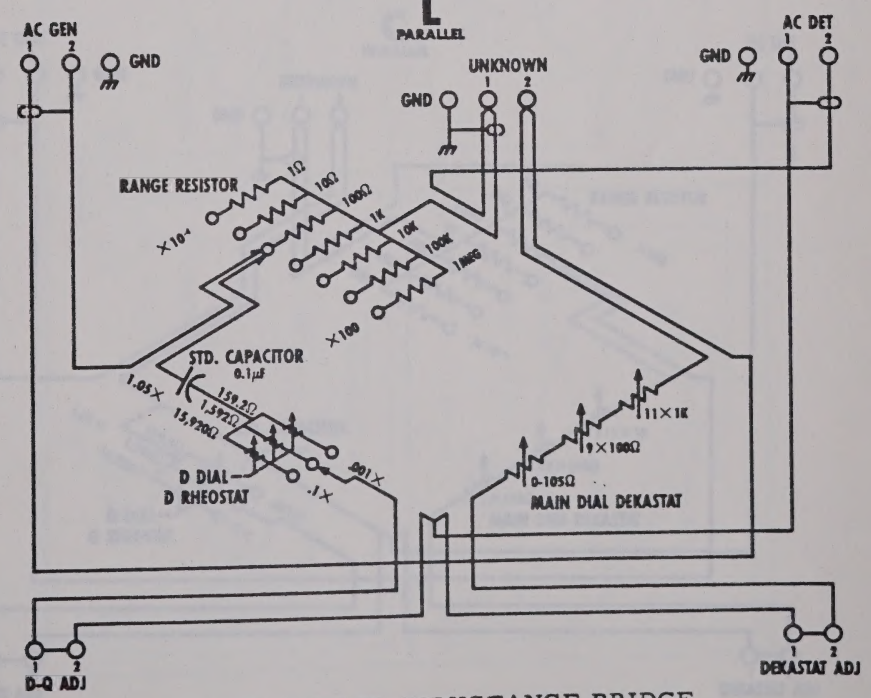

4.2 CONDUCTANCE BRIDGE



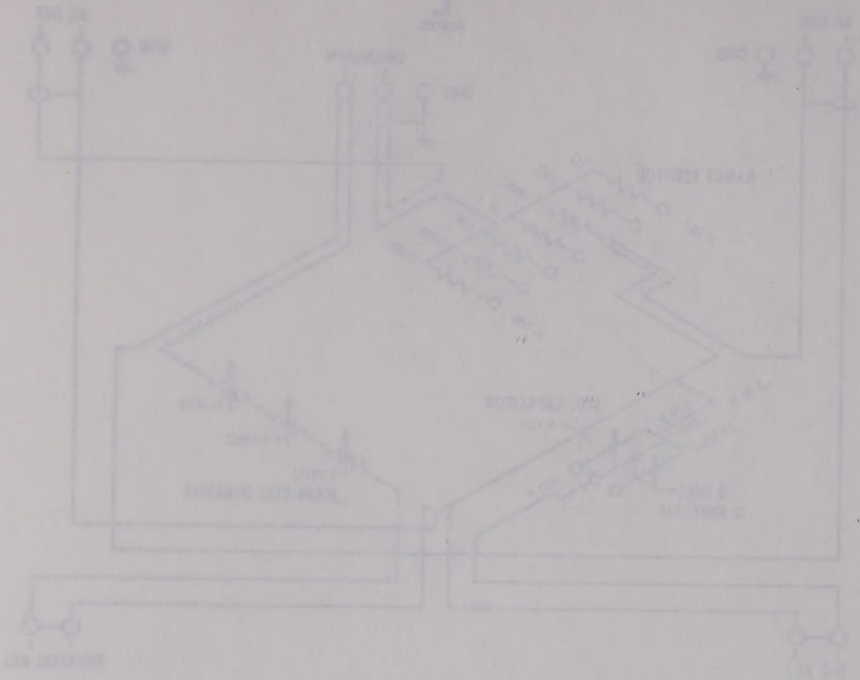


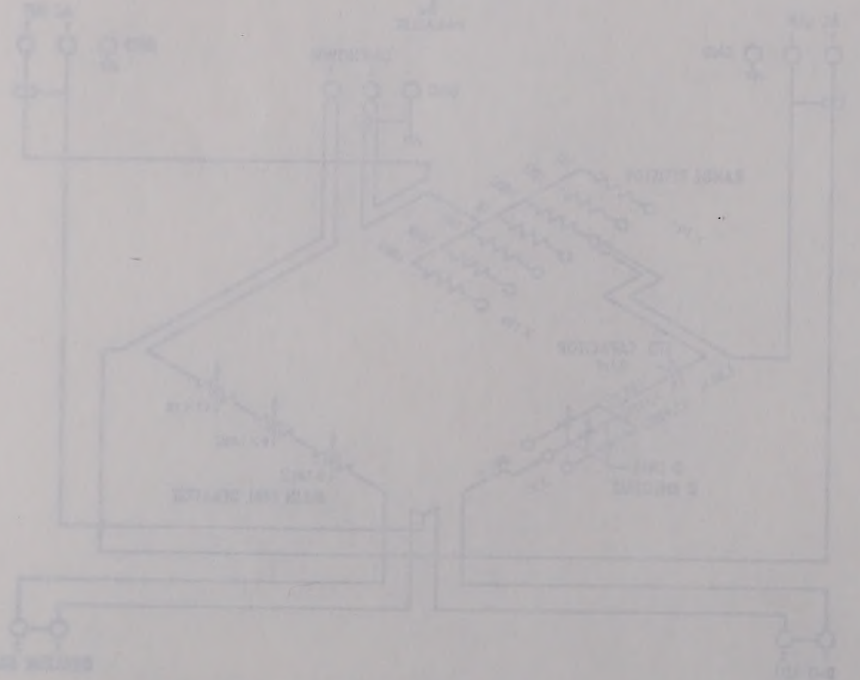


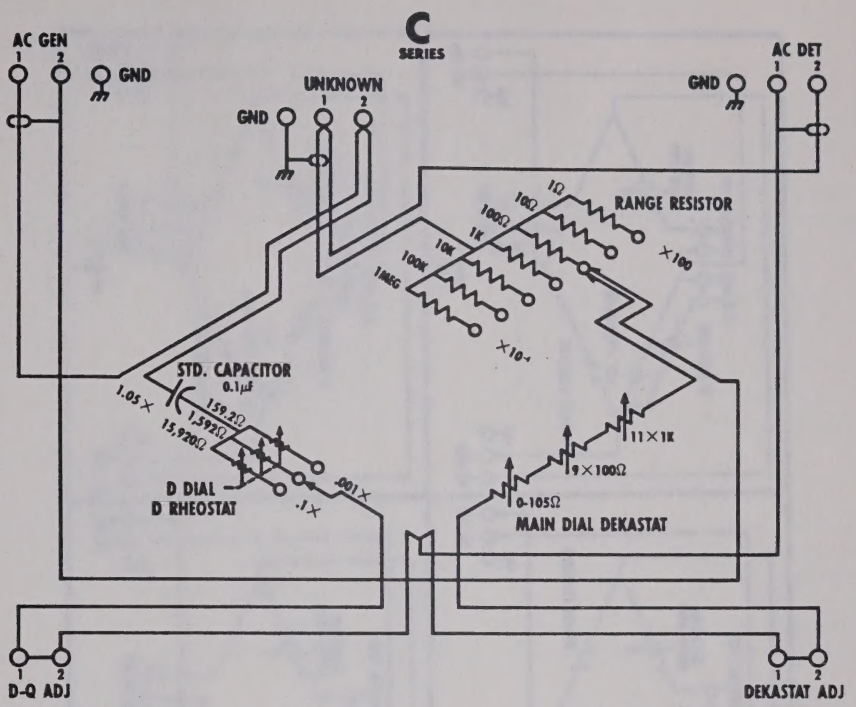

4.3 SERIES INDUCTANCE BRIDGE



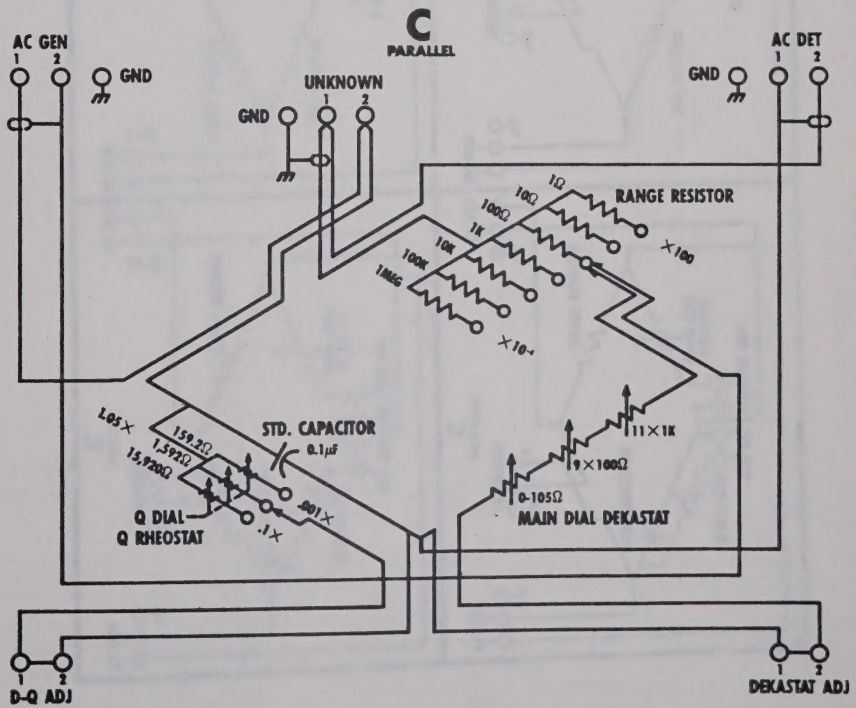

4.4 PARALLEL INDUCTANCE BRIDGE



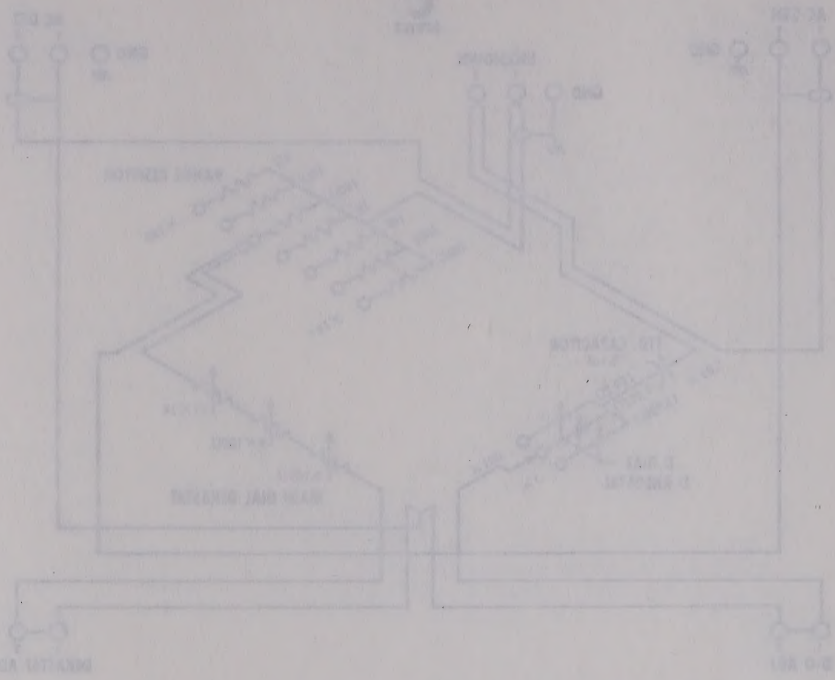


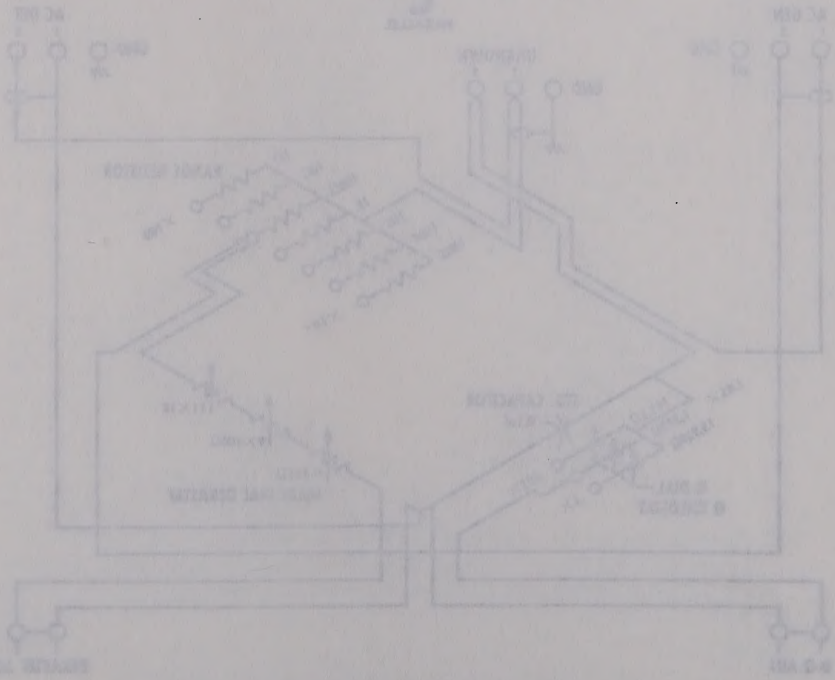


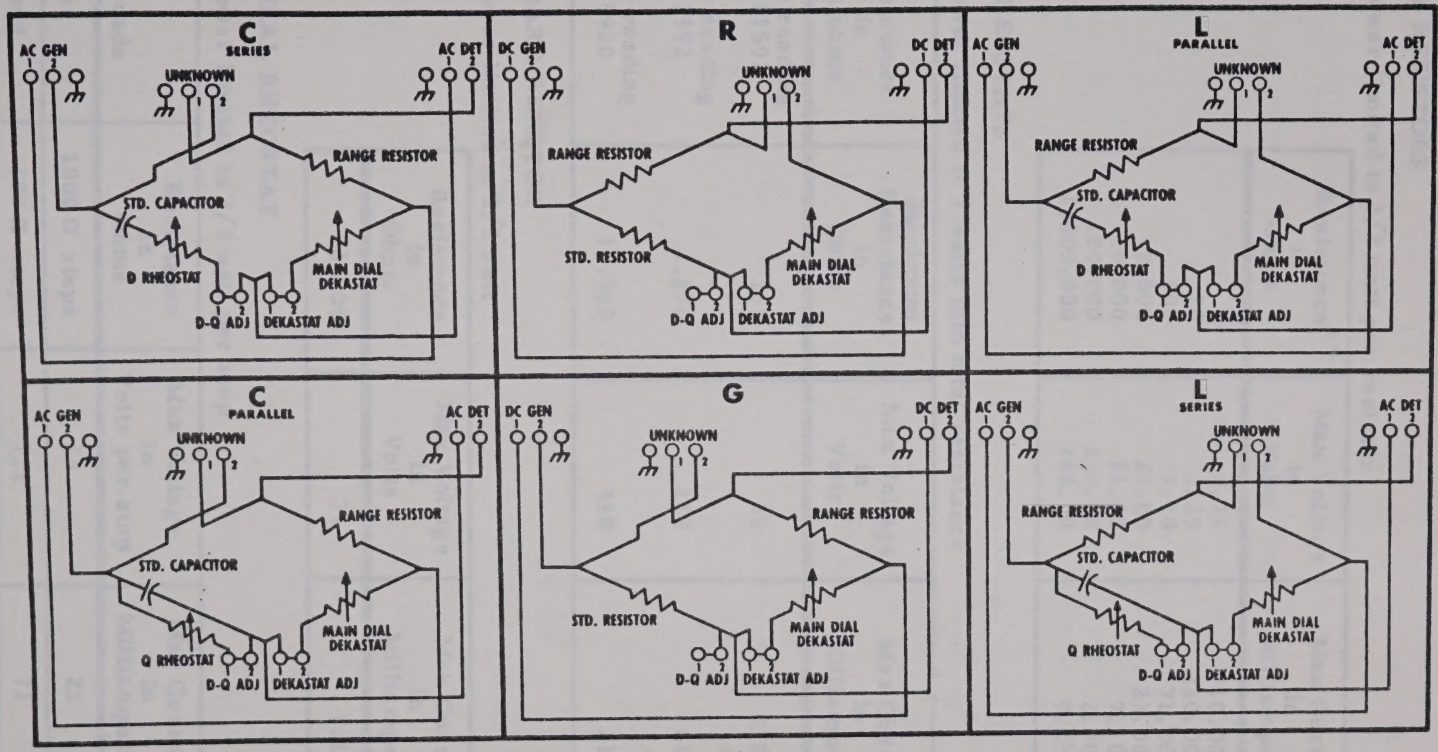

4.5 SERIES CAPACITANCE BRIDGE



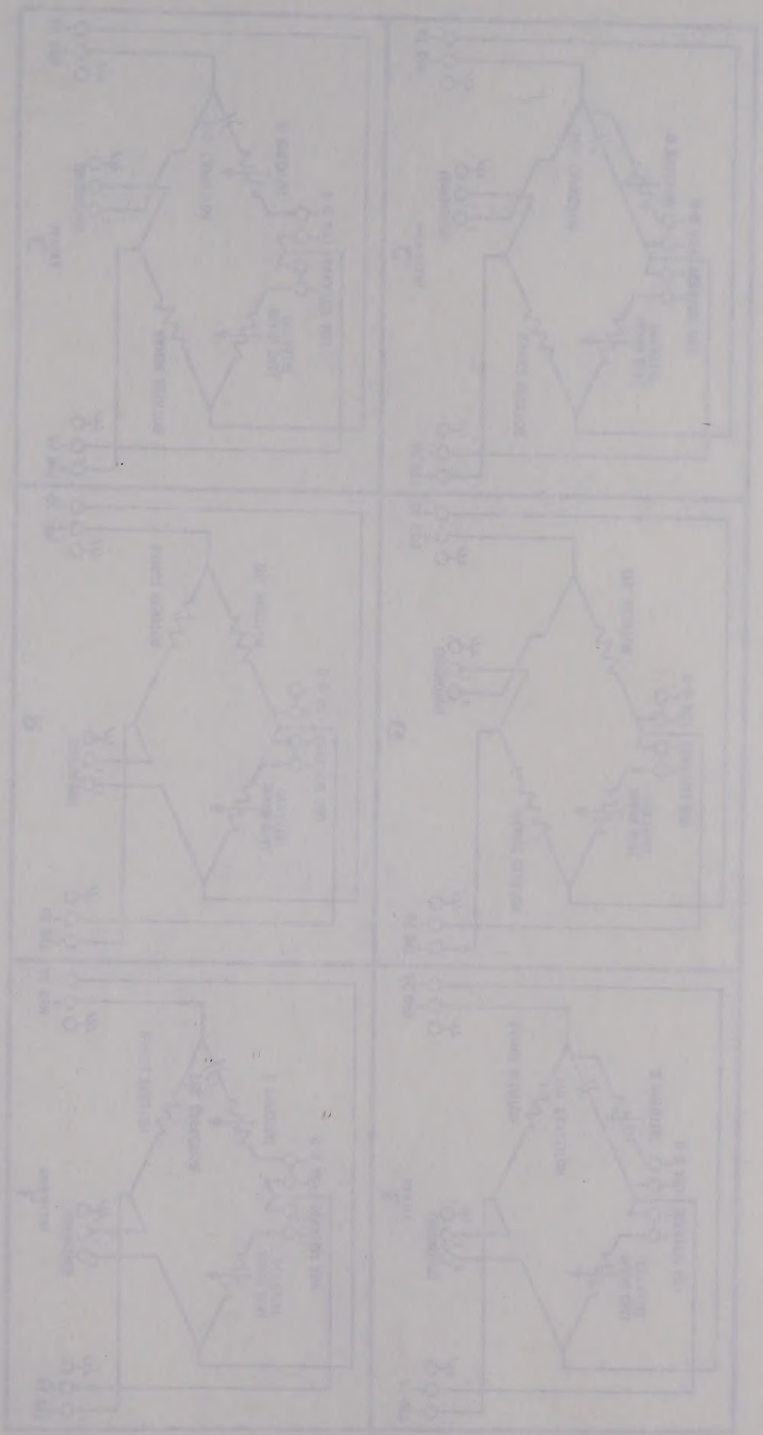

4.6 PARALLEL CAPACITANCE BRIDGE








4.7 BASIC CIRCUITS



## 5. BRIDGE ELEMENT VOLTAGE AND CURRENT LIMITS

### RANGE RESISTORS

Safe Power limited to 1/2 watt per resistor

| Resistance in Ohms | Max Voltage in Volts | Max Current in Milliamperes |
|---|---|---|
| 1 | 0.71 | 710.00 |
| 10 | 2.30 | 230.00 |
| 100 | 7.10 | 71.00 |
| 1,000 | 23.00 | 23.00 |
| 10,000 | 71.00 | 7.10 |
| 100,000 | 230.00 | 2.30 |
| 1,000,000 | 250.00 | 0.25 |

### D-Q RHEOSTATS

Safe power limited to 7 watts into total resistance

| Resistance in Kilohms | Maximum Resistance in Ohms | Max Voltage in Volts | Max Current in Milliamperes |
|---|---|---|---|
| D-Q reading x 0.01592 | 166 | 35 | 210 |
| D-Q reading x 0.1592 | 1,670 | 110 | 68 |
| D-Q reading x 1.5920 | 16,750 | 350 | 21 |

### STANDARD RESISTOR

Safe power limited to 1/2 watt

| Resistance in Ohms | Max Voltage in Volts | Max Current in Milliamperes |
|---|---|---|
| 10,000 | 71 | 7.1 |

### MAIN DIAL RHEOSTAT

Safe power limited to 1/2 watt per step

| Decade | Resistance in Ohms | Max Voltage in Volts per step | Max Current in Milliamperes |
|---|---|---|---|
| First | 1000 Ω steps | 23 | 23 |
| Second | 100 Ω steps | 7.1 | 71 |
| Rheostat | 0 - 105 | 28 at max | 270 |

| Resistance in Ohms | Max Voltage in Volts | Max Current in Milliamperes |
|---|---|---|
| 1 | 0.71 | 710.00 |
| 10 | 2.30 | 230.00 |
| 100 | 7.10 | 71.00 |
| 1,000 | 23.00 | 23.00 |
| 10,000 | 71.00 | 7.10 |
| 100,000 | 230.00 | 2.30 |
| 1,000,000 | 250.00 | 0.25 |

D-Q RHEOSTATS

Each power limited to 7 watts plus total resistance

| Resistance in Kilohms | Maximum Resistance in Ohms | Max Voltage in Volts | Max Current in Milliamperes |
|---|---|---|---|
| D-Q reading x 0.01372 | 168 | 35 | 210 |
| D-Q reading x 0.1372 | 1,670 | 110 | 68 |
| D-Q reading x 1.3710 | 16,750 | 350 | 21 |

STANDARD RESISTOR

Each power limited to 1/2 watt

| Resistance in Ohms | Max Voltage in Volts | Max Current in Milliamperes |
|---|---|---|
| 10,000 | 71 | 7.1 |

MAIN DIAL RHEOSTAT

Each power limited to 1/2 watt per step

| Decade | Resistance in Ohms | Max Voltage in Volts per step | Max Current in Milliamperes |
|---|---|---|---|
| Zero-t | 1000 Ω steps | 27 | 29 |
| Second | 100 Ω steps | 7.1 | 71 |
| Remainder | 0 - 10Ω | 10 V max | 250 |

## 6. CONVENIENT AUDIO FREQUENCY UNITS

For measurement and calculation in the audio frequency range the conventional electrical units are often inconvenient. A consistent set of units can be chosen so that the numerical values commonly encountered will be more practical while at the same time the equations used in calculations will not require any troublesome conversion constants. If either set of units listed below is followed consistently, the equations used for calculations will be unaltered. For example, E = IR holds true equally well with E in volts, I in amperes, and R in ohms; or with E in volts, I in milliamperes and R in kilohms. The 291 dials read directly in these "convenient" units.

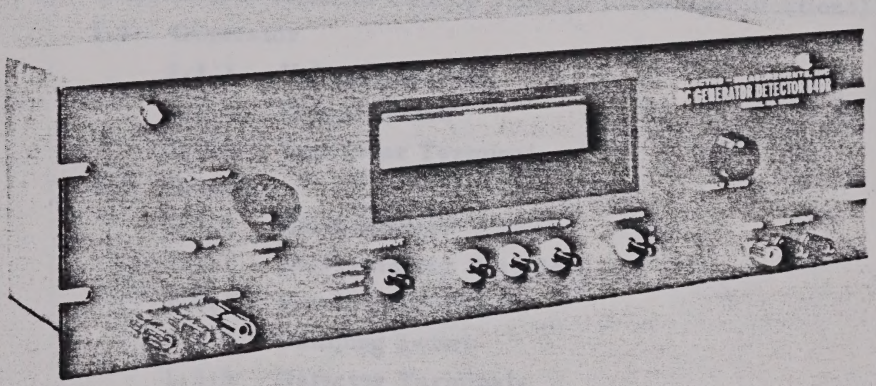
| Function | Conventional Units | Convenient Audio Frequency Units |
|---|---|---|
| $\omega$ | radian/sec = $2\pi f_{cps}$ | kiloradian/sec = $2\pi f_{kc}$ |
| f | cps | kc |
| t | second | millisecond |
| C | farad | microfarad |
| Z, R and X | ohm | kilohm |
| L | henry | henry |
| I | ampere | milliamp |
| E | volt | volt |
| P | watt | milliwatt |
| Q and D | per unit ratio | per unit ratio |

esi *Instruction Manual*

ELECTRO - MEASUREMENTS INC.
7524 S.W. MACADAM • PORTLAND 19, OREGON

BRIDGES
AND
ACCESSORIES

NOVEMBER 1959
REPLACES APRIL 1959




## Model 840-R

# DC GENERATOR-DETECTOR

*excellent scientific instruments*

esi

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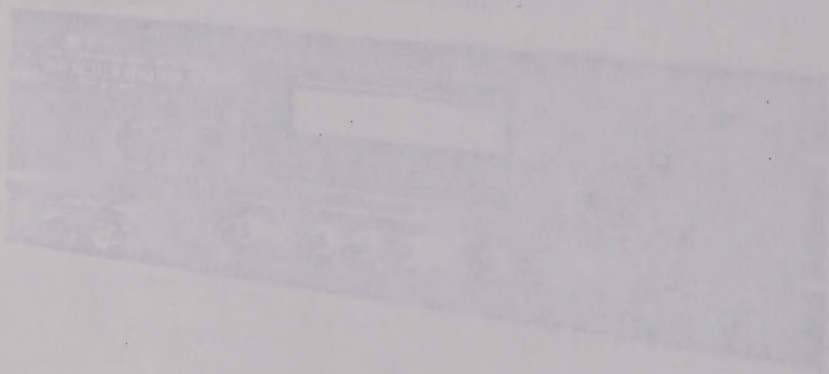
Litho in U.S.A.



INSTRUCTION MANUAL

for

MODEL 840-R DC GENERATOR AND DETECTOR

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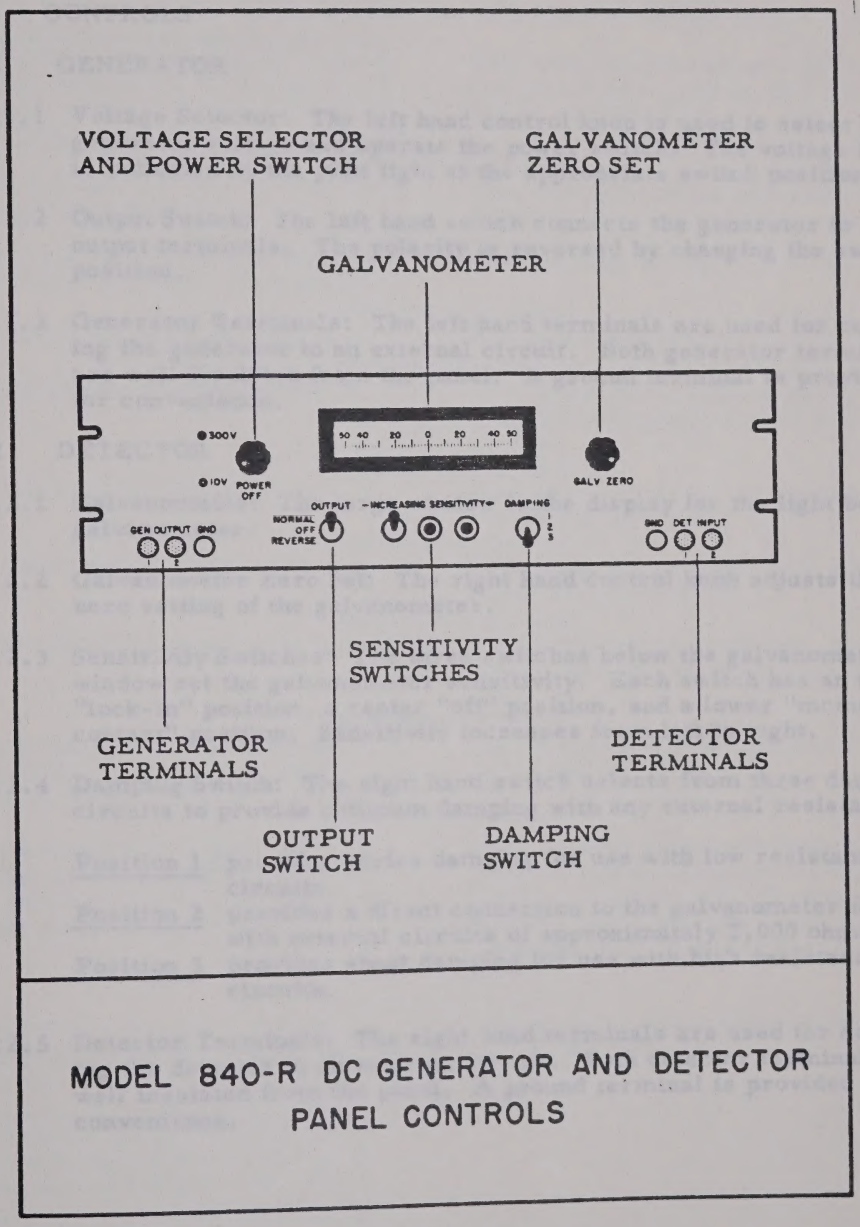
     - 1.1.1 Voltage Selector
     - 1.1.2 Output Switch
     - 1.1.3 Generator Terminals
   - 1.2 Detector
     - 1.2.1 Galvanometer
     - 1.2.2 Galvanometer Zero Set
     - 1.2.3 Sensitivity Switches
     - 1.2.4 Damping Switch
     - 1.2.5 Detector Terminals
2. Using the 840-R
3. Circuit Diagram




MODEL 840-R DC GENERATOR AND DETECTOR
PANEL CONTROLS

MODEL 840-R DC GENERATOR AND DETECTOR
PANEL CONTROLS

# 1. CONTROLS

## 1.1 GENERATOR

1.1.1 Voltage Selector: The left hand control knob is used to select the generator voltage and operate the power switch. The voltage in use is indicated by the pilot light at the appropriate switch position.

1.1.2 Output Switch: The left hand switch connects the generator to the output terminals. The polarity is reversed by changing the switch position.

1.1.3 Generator Terminals: The left hand terminals are used for connecting the generator to an external circuit. Both generator terminals are well insulated from the panel. A ground terminal is provided for convenience.

## 1.2 DETECTOR

1.2.1 Galvanometer: The large window is the display for the light beam galvanometer.

1.2.2 Galvanometer Zero Set: The right hand control knob adjusts the zero setting of the galvanometer.

1.2.3 Sensitivity Switches: The three switches below the galvanometer window set the galvanometer sensitivity. Each switch has an upper "lock-in" position, a center "off" position, and a lower "momentary-contact" position. Sensitivity increases from left to right.

1.2.4 Damping Switch: The right hand switch selects from three damping circuits to provide optimum damping with any external resistance.

Position 1 provides series damping for use with low resistance circuits.

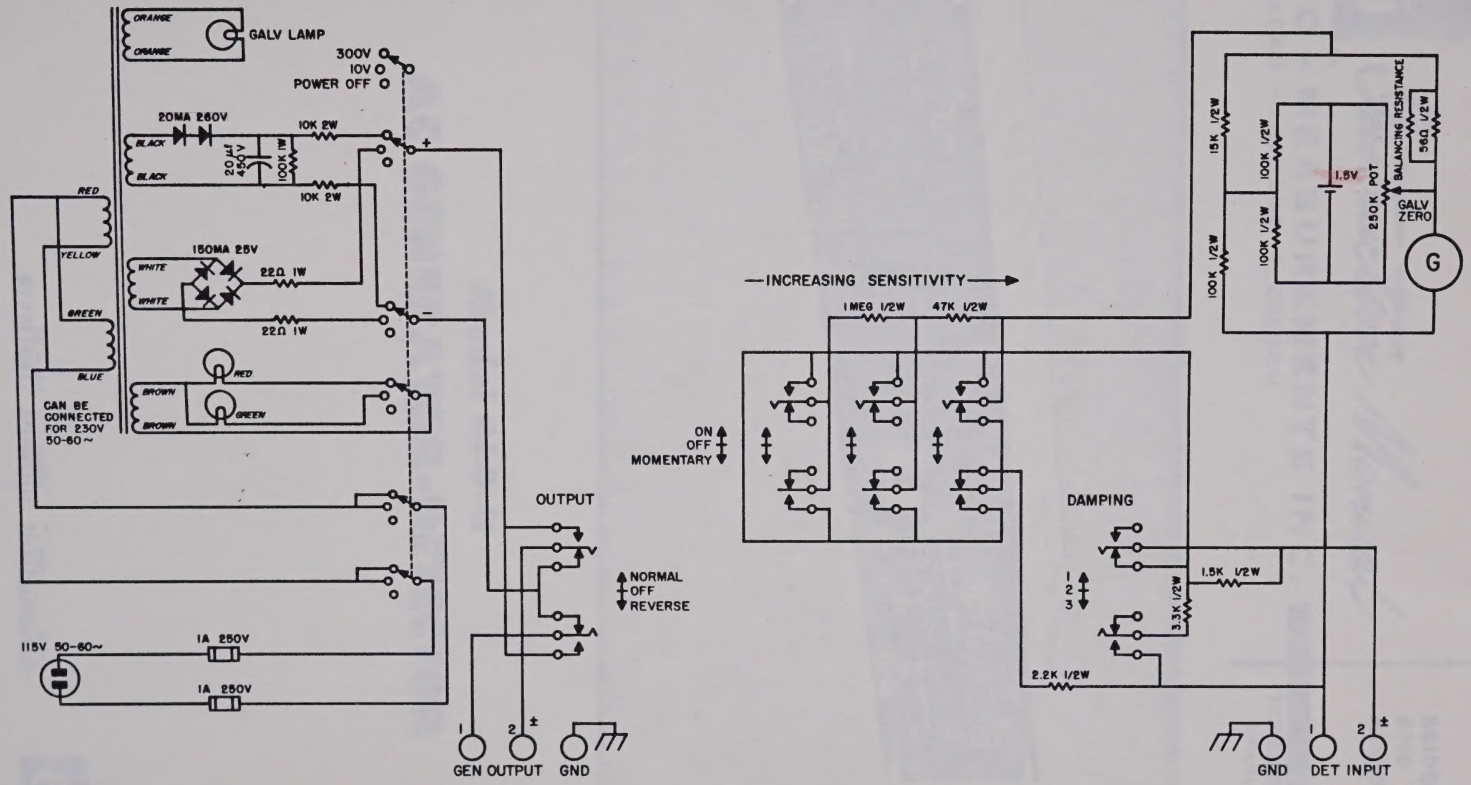
Position 2 provides a direct connection to the galvanometer for use with external circuits of approximately 2,000 ohms.

Position 3 provides shunt damping for use with high resistance circuits.

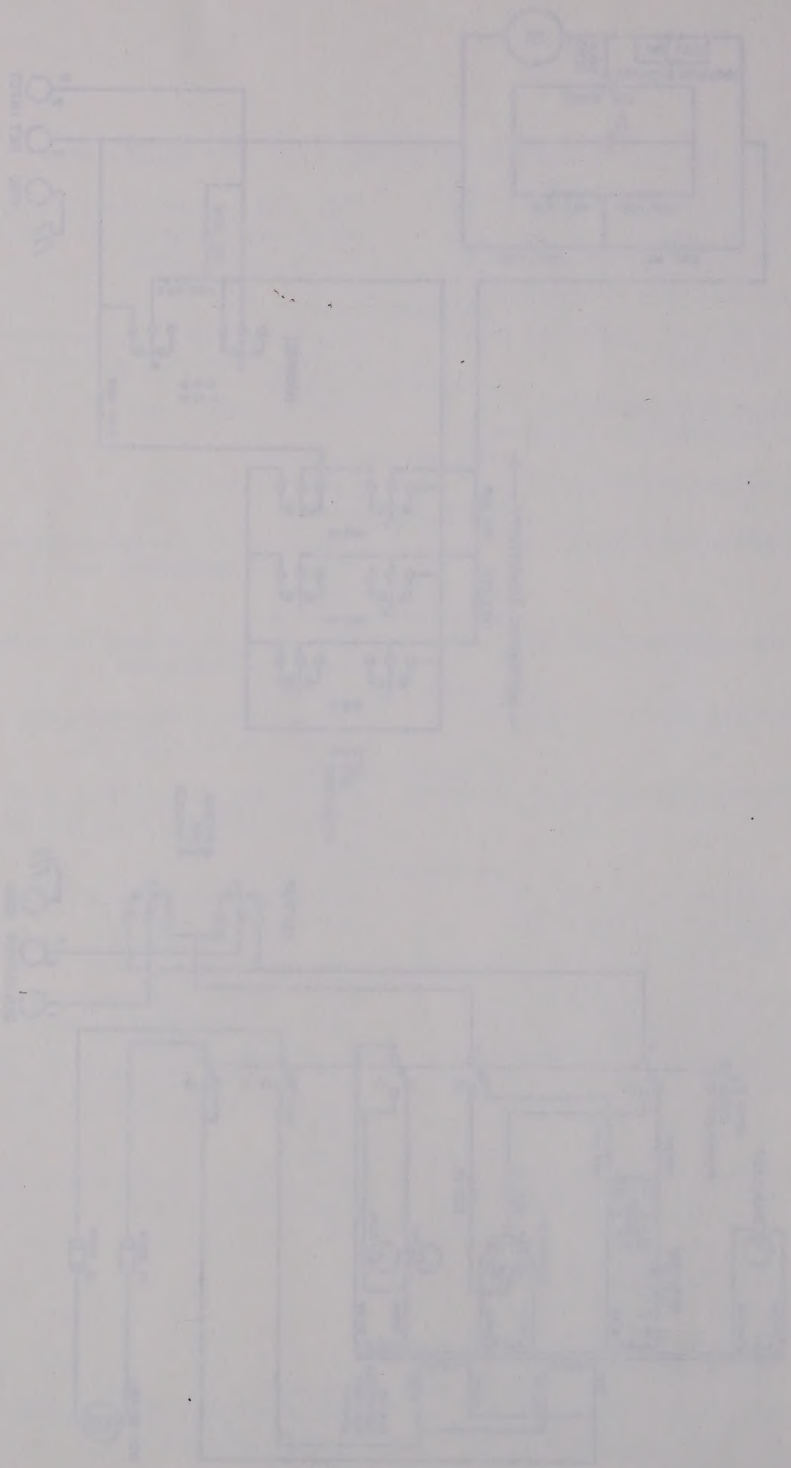
1.2.5 Detector Terminals: The right hand terminals are used for connecting the detector to an external circuit. Both detector terminals are well insulated from the panel. A ground terminal is provided for convenience.

## 2. USING THE 840-R DC GENERATOR DETECTOR *the* esi *way*

| | |
|---|---|
| **WARNING: Before touching generator terminals, or any part of circuit, always set output switch to OFF.** | This will remove the voltage from the generator terminals so that connections can be made safely. |
| SET ALL LEVER SWITCHES TO CENTER "OFF" POSITION. | This disconnects the generator and detector from the terminals on the panel. |
| CONNECT GENERATOR OUTPUT AND DETECTOR INPUT TO BRIDGE | Note warning above. |
| CHECK GALVANOMETER ZERO | Adjust if necessary. |
| SET GENERATOR VOLTAGE TO 10 VOLTS | This turns on the galvanometer light beam and energizes the 10 volt power supply. |
| SET DAMPING SWITCH TO POSITION 3 | This assures proper functioning of the sensitivity switches. |
| SET OUTPUT SWITCH TO "NORMAL" | This connects the generator terminals in the normal polarity. |
| TURN ON LOWEST SENSITIVITY SWITCH | Switch may be pressed down for momentary contact, or up for lock-in contact. |
| BALANCE BRIDGE, TURNING ON HIGHER SENSITIVITY SWITCHES AS NULL IS APPROACHED | Lower sensitivity switches can be left on if desired. |
| IF GALVANOMETER RESPONSE IS SLUGGISH WHEN HIGHEST SENSITIVITY SWITCH IS ON, CHANGE DAMPING SWITCH TO POSITION 1 OR 2 | When highest sensitivity switch is on, position 2 of damping switch will give maximum sensitivity. If response is still sluggish, position 1 will improve response time, but may decrease sensitivity. |
| IF SENSITIVITY IS LOW, TRY INCREASING OUTPUT VOLTAGE TO 300 VOLTS | This supplies more power to high resistance circuits. |
| **WARNING: This 300 volts may appear on any terminal of the generator or bridge. Use caution!** | |
| BEFORE MAKING ANY CIRCUIT CHANGES, RETURN SWITCHES TO:<br>OUTPUT------OFF<br>SENSITIVITY--OFF | These settings will protect the bridge and the operator. |




3. 840-R DC GENERATOR DETECTOR CIRCUIT DIAGRAM



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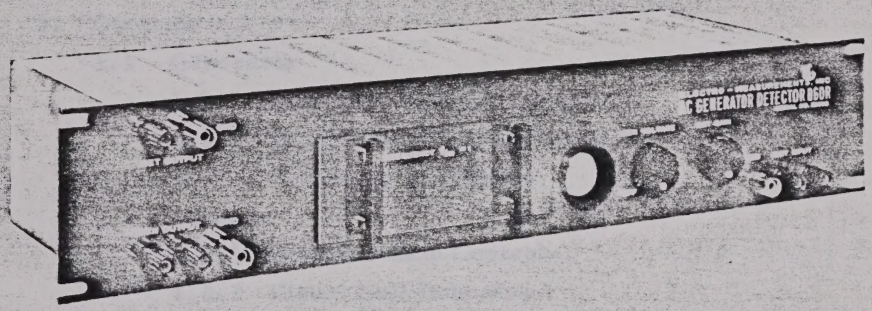
# Instruction Manual

BRIDGES AND ACCESSORIES

ELECTRO - MEASUREMENTS INC.
7524 S.W. MACADAM • PORTLAND 19, OREGON

NOVEMBER 1959
REPLACES APRIL 1959




## Model 860-R

# AC GENERATOR-DETECTOR

excellent scientific instruments

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Litho in U.S.A.

# INSTRUCTION MANUAL
for
# MODEL 860-R AC GENERATOR AND DETECTOR

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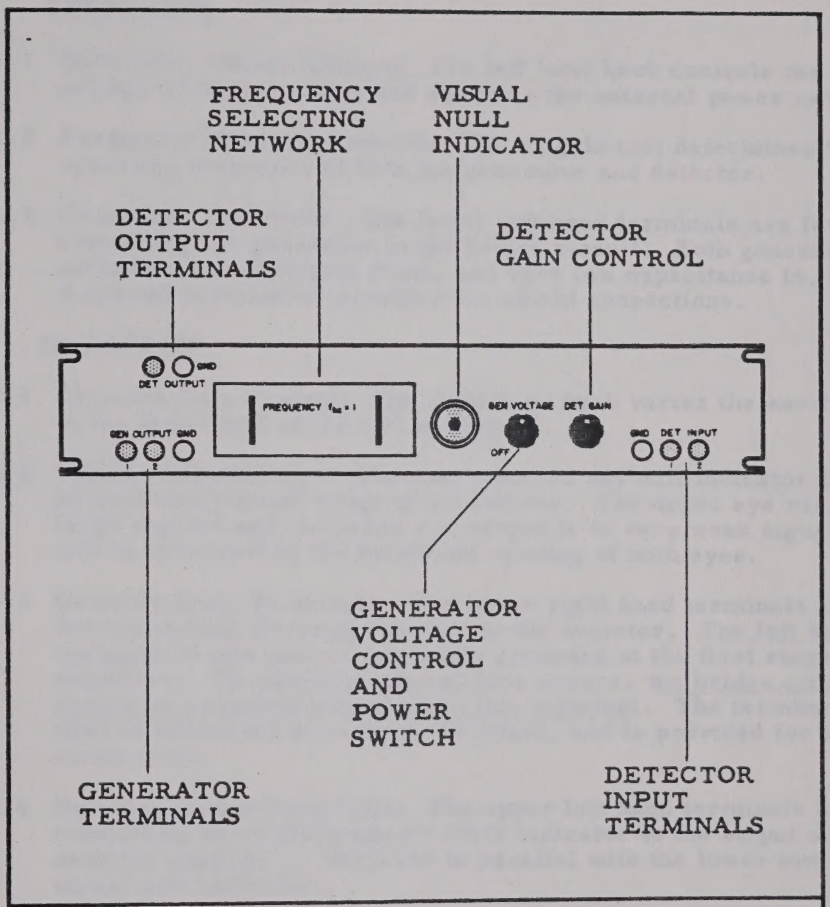



MODEL 860-R AC GENERATOR AND DETECTOR PANEL CONTROLS

MODEL 800-R AC GENERATOR AND DETECTOR
PANEL CONTROLS

# 1. CONTROLS

## 1.1 GENERATOR

1.1.1 Generator Voltage Control: The left hand knob controls the output voltage of the generator and operates the external power switch.

1.1.2 Frequency Selecting Network: The plug-in unit determines the operating frequency of both the generator and detector.

1.1.3 Generator Terminals: The lower left hand terminals are for connecting the generator to the bridge circuit. Both generator terminals are insulated from, and have low capacitance to, ground. A ground terminal is provided for shield connections.

## 1.2 DETECTOR

1.2.1 Detector Gain Control: The right hand knob varies the sensitivity of the lower half of the null indicator.

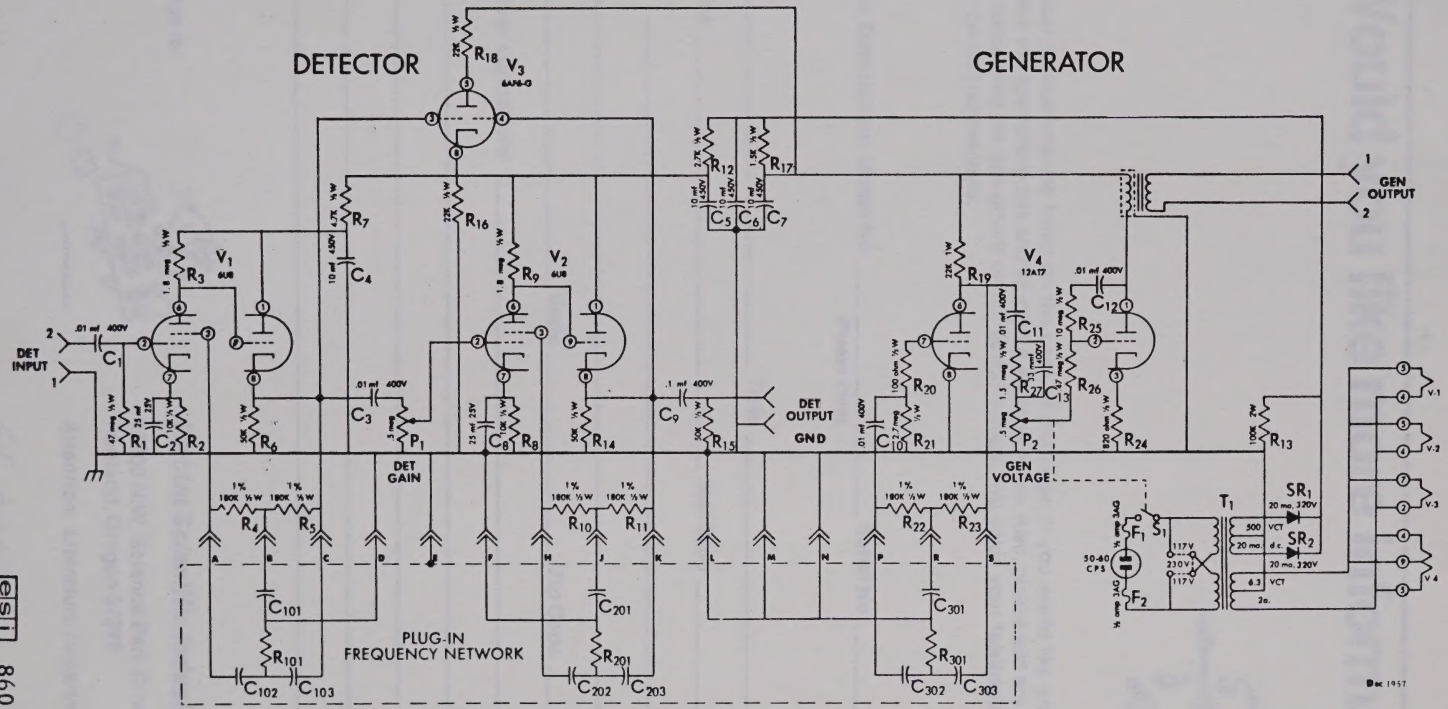
1.2.2 Visual Null Indicator: The dual electron ray null indicator provides an extremely broad range of sensitivity. The upper eye responds to large signals and the lower eye responds to very weak signals. A null is indicated by the maximum opening of both eyes.

1.2.3 Detector Input Terminals: The lower right hand terminals are used for connecting the bridge circuit to the detector. The left hand terminal of this pair is internally grounded at the first stage of the amplifier. To minimize ground loop errors, the bridge circuit should be grounded only through this terminal. The terminal marked GND is connected directly to the panel, and is provided for shield connections.

1.2.4 Detector Output Terminals: The upper left hand terminals are for connecting an oscilloscope or other indicator to the output of the detector amplifier. They are in parallel with the lower eye of the visual null indicator.

## 2. USING THE 860-R AC GENERATOR AND DETECTOR *the* esi *way*

| | |
|---|---|
| CONNECT GENERATOR OUTPUT AND DETECTOR INPUT TO BRIDGE | Set the generator voltage control to off for safety. |
| SET GENERATOR VOLTAGE CONTROL WITH DOT UP | This turns on the power supply, and provides sufficient generator voltage for most measurements. |
| SET DETECTOR GAIN CONTROL WITH DOT UP | This provides sufficient detector sensitivity for most measurements. |
| BALANCE BRIDGE | The null is indicated by maximum opening of both eyes. The pattern edges will be sharp at a null but will remain "fuzzy" for a minimum which is not a true null. |
| IF ADDITIONAL SENSITIVITY IS NEEDED, INCREASE THE DETECTOR GAIN AND/OR GENERATOR VOLTAGE. | Maximum sensitivity may be needed for bridge measurements of very high or very low impedance components. |




3. 860-R AC GENERATOR-DETECTOR CIRCUIT DIAGRAM

# Would you like more information?

ESI technical publications are listed on the back of this page. If you would like any of these, simply check the appropriate box and fill in your address below. Also, please add any comments you have concerning the instrument or instruction manual. We value your feedback to help us improve or correct our manuals.

Instrument Description: Model No. _____ Serial No. _____
(Please Print)

Name _____ Title _____

Department _____ Mail Stop _____

Company _____

Address _____

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Comments or corrections _____

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61 pages including this page

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